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IDENTIFIERS Aerodynamics; Military Curriculum Project

ABSTRACT

These teacher and student materials for the first section of a two-phase secondary/postsecondary level course for aviation machinists make up one of a number of military-developed curriculum packages selected for adaptation to vocational instruction and curriculum development in a civilian setting. The purpose of the course is to enable students to maintain aircraft engines, perform intermediate and major inspections on engines and their related systems, field test and adjust components of engines, and replace compressor turbine blades and combustion chamber liners. This phase, Airman Preparatory, contains 5 weeks of instruction totaling 131 hours: School Indoctrination and Mathematics (10 lessons, 23 hours); Physics (11 lessons and a math review, 27 hours); Basic Electricity (10 lessons, 27 hours); Aerodynamics, Weight and Balance, and Instruments (7 lessons, 27 hours); and Hardware and Handtools (4 lessons, 27 hours). Instructor materials include a curriculum outline containing a weekly breakdown of lessons, topic objectives, equipment and furniture requirements, training aids and devices needed, and publications used as texts or references. Student materials are a study guide/workbook, six programmed texts, and chapters from three Navy training manuals. (YLB)

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MILITARY CURRICULUM MATERIALS

The military-developed curriculum materials in this course package were selected by the National Center for Research in Vocational Education Military Curriculum Project for dissemination to the six regional Curriculum Coordination Centers and other instructional materials agencies. The purpose of disseminating these courses was to make curriculum materials developed by the military more accessible to vocational educators in the civilian setting.

The course materials were acquired, evaluated by project staff and practitioners in the field, and prepared for dissemination. Materials which were specific to the military were deleted, copyrighted materials were either omitted or approval for their use was obtained. These course packages contain curriculum resource materials which can be adapted to support vocational instruction and curriculum development.

The National Center Mission Statement

The National Center for Research in Vocational Education's mission is to increase the ability of diverse agencies, institutions, and organizations to solve educational problems relating to individual career planning, preparation, and progression. The National Center fulfills its mission by:

- Generating knowledge through research
- Developing educational programs and products
- Evaluating individual program needs and outcomes
- Installing educational programs and products
- Operating information systems and services
- Conducting leadership development and training programs

FOR FURTHER INFORMATION ABOUT
Military Curriculum Materials
WRITE OR CALL
Program Information Office
The National Center for Research in Vocational Education
The Ohio State University
1960 Kenny Road, Columbus, Ohio 43210
Telephone: 614/486-3655 or Toll Free 800/848-4815 within the continental U.S. (except Ohio)

THE NATIONAL CENTER
FOR RESEARCH IN VOCATIONAL EDUCATION

Military Curriculum Materials for Vocational and Technical Education

Information and Field Services Division

The National Center for Research in Vocational Education

Military Curriculum Materials Dissemination Is . . .

an activity to increase the accessibility of military developed curriculum materials to vocational and technical educators.

This project, funded by the U.S. Office of Education, includes the identification and acquisition of curriculum materials in print form from the Coast Guard, Air Force, Army, Marine Corps and Navy.

Access to military curriculum materials is provided through a "Joint Memorandum of Understanding" between the U.S. Office of Education and the Department of Defense.

The acquired materials are reviewed by staff and subject matter specialists, and courses deemed applicable to vocational and technical education are selected for dissemination.

The National Center for Research in Vocational Education is the U.S. Office of Education's designated representative to acquire the materials and conduct the project activities.

Project Staff:

Wesley E. Budke, Ph.D., Director
National Center Clearinghouse

Shirley A. Chase, Ph.D.
Project Director

What Materials Are Available?

One hundred twenty courses on microfiche (thirteen in paper form) and descriptions of each have been provided to the vocational Curriculum Coordination Centers and other instructional materials agencies for dissemination.

Course materials include programmed instruction, curriculum outlines, instructor guides, student workbooks and technical manuals.

The 120 courses represent the following sixteen vocational subject areas:

- Agriculture
- Aviation
- Building & Construction Trades
- Clerical Occupations
- Communications
- Drafting
- Electronics
- Engine Mechanics
- Food Service
- Health
- Heating & Air Conditioning
- Machine Shop
- Management & Supervision
- Meteorology & Navigation
- Photography
- Public Service

The number of courses and the subject areas represented will expand as additional materials with application to vocational and technical education are identified and selected for dissemination.

How Can These Materials Be Obtained?

Contact the Curriculum Coordination Center in your region for information on obtaining materials (e.g., availability and cost). They will respond to your request directly or refer you to an instructional materials agency closer to you.

CURRICULUM COORDINATION CENTERS

EAST CENTRAL
Rebecca S. Douglass
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100 North First Street
Springfield, IL 62777
217/782-0759

MIDWEST
Robert Patton
Director
1515 West Sixth Ave.
Stillwater, OK 74704
405/377-2000

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Olympia, WA 98504
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Director
1776 University Ave.
Honolulu, HI 96822
808/948-7834

AVIATION MACHINIST'S MATE, PHASE 1

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Basic Electricity

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Aviation Electrician's Mate 3 & 2

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Airman

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AVIATION MACHINIST'S MATE, PHASE I

Classroom Course

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Developed by:

United States Coast Guard

Development and Review Dates

March 19, 1975

D.O.T. No.:
639.281

Occupational Area:

Aviation

Target Audiences:

Grades 11-adult

Print Pages:

610

Cost:

Availability:
Military Curriculum Project, The Center for Vocational Education, 1960 Kenny Rd., Columbus, OH 43210

Contents:	Type of Materials: Lesson Plans:	Type of Materials: Programmed Text:	Type of Materials: Student Workbook:	Type of Materials: Handouts:	Type of Materials: Text Materials:	Type of Materials: Audio-Visuals:	Instructional Design: Performance Objectives:	Instructional Design: Tests:	Instructional Design: Review Exercises:	Instructional Design: Additional Materials Required:	Type of Instruction: Group Instruction:	Type of Instruction: Individualized:
			No. of pages									
Phase I — *Airman Preparatory*												
Indoctrination and Math	●		24		●		●				●	
Physics	●		39		●		●				●	
Basic Electricity	●	●	35		●		●				●	
Aerodynamics, Weight and Balance, and Instruments	●	●			●		●				●	
Hardware and Handtools	●				●		●				●	

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Expires July 1, 1978

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Course Description

This is the first section of a two-phase course for Aviation Machinists. Students completing the entire course will be able to maintain aircraft engines, perform intermediate and major inspections on engines and their related systems; field test and adjust components of engines including fuel pumps, valves, regulators, magnetos, and replace compressor turbine blades and combustion chamber liners. A third phase deals with specific military aircraft and has been deleted. Phase I—*Airman Preparatory* contains five "weeks" of instruction totaling 131 hours. A sixth "week" on military publications was deleted.

Week 1 — **School Indoctrination and Mathematics** contains ten lessons totaling 23 hours of instruction. A four hour introduction to the school was deleted. The lesson topics and respective hours follow:

1-1 Introduction to Mathematics (2 hours)
1-2 Fractions (3 hours)
1-3 Decimals (2 hours)
1-4 Percentages (2 hours)
1-5 Positive and Negative Numbers (1 hour)
1-6 Ratio and Proportion (2 hours)
1-7 Formulas (2 hours)
1-8 Angles (2 hours)
1-9 Trianges (2 hours)
1-10 Areas and Volumes (5 hours)

Week 2 — **Physics** contains eleven lessons and a math review totaling 27 hours of instruction.

Math Review (3 hours)
2-1 Matter and Electron Theory (2 hours)
2-2 Force and Pressure (2 hours)
2-3 Pascal's Law (2 hours)
2-4 Mechanics of Gases (4 hours)
2-5 Mechanics of Heat (4 hours)
2-6 Introduction to Diaphragm and Fluid Type Instruments (2 hours)
2-7 Force and Motion (2 hours)
2-8 Work and Power (2 hours)
2-9 Principles of Machines (2 hours)
2-10 Introduction to Gears (1 hour)
2-11 Introduction to Gyro Instruments (1 hour)

Week 3 — **Basic Electricity** contains ten lessons covering 27 hours of instruction.

3-1 Introduction to Static Electricity (2 hours)
3-2 Introduction to Dynamic Electricity (2 hours)
3-3 Introduction to Ohm's Law and the Rheostat (2 hours)
3-4 Introduction to Series Circuits (3 hours)
3-5 Introduction to Parallel Circuits (3 hours)
3-6 Introduction to Magnetic Theory & Electromagnetism (3 hours)
3-7 Introduction to Electrical Components (4 hours)
3-8 Introduction to Safety Devices and Controls—Voltage Regulators, Reverse Current Relays, Circuit Breakers (4 hours)
3-9 Introduction to Basic Aircraft Electrical Systems (3 hours)
3-10 The Simpson Multimeter (1 hour)

Week 4 — **Aerodynamics, Weight and Balance, and Instruments** contains seven lessons totaling 27 hours of instruction.

4-1 Introduction to Aircraft (6 hours)
4-2 Fundamental Rotation and Stresses (2.5 hours)
4-3 Aircraft Controls and Systems (3.5 hours)
4-4 Atmospheric Effects on Aircraft (1.5 hours)
4-5 Introduction to Aerodynamics (4.5 hours)
4-6 Rotary Wing Aerodynamics (3 hours)
4-7 Introduction to Weight and Balance (6 hours)

Week 5 — **Hardware and Handtools** contains four lessons covering 27 hours of instruction.

5-1 Introduction to Hardware and Materials (4 hours)
5-2 Introduction to Common Handtools (6.5 hours)
5-3 Nuts, Blots, Screws, Fasteners and Special Aircraft Hardware (6.5 hours)
5-4 Safety Devices and Safety Wiring Practical (10 hours)

This section of the two phase course contains both teacher and student materials. Printed instructor materials include a curriculum outline containing a weekly breakdown of lessons, topic objectives, equipment and furniture requirements, training aids and devices needed, publications used as texts or references, and space requirements. The materials for the students are not complete. They include a study guide/workbook covering math, physics, and electricity; six programmed texts covering matter, atomic structure, the principles of electricity, parallel circuits, aircraft nomenclature, and part two of helo aerodynamics; and miscellaneous chapters from three Navy training manuals. The training manuals used are *Basic Electricity, NAVPERS 10086-B; Airman, NAVPERS 10307-C;* and *Aviation Electrician's Mate 3 & 2, NAVEDTRA 10348-D.* Several other military and commercial texts were recommended as texts and references but are not provided. No specific audiovisuals were recommended. These materials can be adapted for individualized instruction or used as remedial or independent study in electronics or aircraft maintenance courses.

[illegible]

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CURRICULUM OUTLINE

FOR

CLASS "A" AD SCHOOL

2-5 and
2-6

A 21 WEEK COURSE

CLASSIFICATION: UNCLASSIFIED

PREPARED BY

USCG AIRCRAFT REPAIR AND SUPPLY CENTER

ELIZABETH CITY, N.C.

Reviewed By SME: G. J. ROY, CAPT, USCG
COMDT (G-EAE)

Approved By: P. E. [illegible]
Chief, Training and Education Division

19 MAR 1975

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1. MISSION: TO PROVIDE AVIATION MACHINIST'S MATE (AD) CANDIDATES WITH THE CLASS "A" LEVEL TRAINING NECESSARY TO FULFILL THE REQUIREMENTS FOR ADVANCEMENT TO AD3 AS SET FORTH IN THE CG-311, ENLISTED RATINGS QUALIFICATION MANUAL.

2. SCOPE: AVIATION MACHINIST'S MATES MAINTAIN AIRCRAFT ENGINES, TURBINE AND RECIPROCATING, AND THEIR RELATED SYSTEMS INCLUDING THE INDUCTION, COOLING, FUEL, OIL, COMPRESSION, COMBUSTION, TURBINE, IGNITION, PROPELLER AND EXHAUST SYSTEMS; PREFLIGHT AIRCRAFT; PERFORM INTERMEDIATE AND MAJOR INSPECTIONS ON ENGINES AND THEIR RELATED SYSTEMS; FIELD TEST AND ADJUST COMPONENTS OF ENGINES INCLUDING FUEL PUMPS, VALVES, REGULATORS, MAGNETOS AND OTHER COMPONENTS OF THE ENGINES AND ENGINE RELATED SYSTEMS; REMOVE, REPAIR AND REPLACE COMPRESSOR TURBINE BLADES AND COMBUSTION CHAMBER LINERS; MAINTAIN AND ADJUST HELICOPTER DRIVE SHAFTING, POWER TRANSMISSIONS, GEAR BOXES AND CLUTCH ASSEMBLIES; PRESERVE AND DEPRESERVE ENGINES, ENGINE ACCESSORIES AND COMPONENTS; AND SUPERVISE ENGINE SHOPS. PRACTICAL FACTORS FOR THE AVIATION MACHINIST'S MATE RATING ARE APPLICABLE TO THE AIRCRAFT AND EQUIPMENT ASSIGNED OR AVAILABLE.

3. OBJECTIVES:

   A. UPON COMPLETION OF THIS COURSE, THE TRAINEE WILL:

      (1) BE ABLE TO FULFILL THE TECHNICAL REQUIREMENTS FOR AVIATION MACHINIST'S MATE, THIRD CLASS, AS ESTABLISHED BY CG-311, ENLISTED RATINGS QUALIFICATIONS MANUAL.

      (2) HAVE DEMONSTRATED THE QUALITIES EXPECTED OF A COAST GUARD PETTY OFFICER.

   B. IN ORDER TO ACHIEVE THESE OBJECTIVES, THE TRAINEE MUST SATISFACTORILY COMPLETE THE CURRICULUM AS LISTED IN THE FOLLOWING PAGES, AND IN A MANNER CONSISTENT WITH AR&SC TRAINING DIVISION POLICIES.

b

Length of Course . . . . 21 Weeks . . . . 819 Hours

Based on a 39.0 hour week.

A training hour represents approximately sixty minutes of actual instruction. There are six such training hours in each day, with each separated by a ten minute break.

Military requirements are met by a fifteen minute period each morning prior to commencement of classes and one hour each Friday afternoon. This includes musters, marching, and classroom instruction.

BREAKDOWN OF TRAINING

1. Technical Training	
a. Classroom	409.0 Hours
b. Line or practical	158.0 Hours
2. Supplementary Training	
a. Military	52.5 Hours
b. Physical	31.5 Hours
3. Miscellaneous	168.0 Hours

AVERAGE WORK WEEK

1. Technical Training	27.0 Hours
2. Military Training	2.5 Hours
3. Physical Training	1.5 Hours
4. Miscellaneous	8.0 Hours

a. Reviewing (Friday afternoon)

b. Testing

c. Cleanup

d. Coffee Breaks

PHASE I (AIRMAN PREPARATORY)

Week 1 AD(A) School Indoctrination & Mathematics

	AD(A) School Indoctrination	4.0
1-1	Introduction to Mathematics	2.0
1-2	Fractions	3.0
1-3	Decimals	2.0
1-4	Percentages	2.0
1-5	Positive and Negative Numbers	1.0
1-6	Ratio and Proportion	2.0
1-7	Formulas	2.0
1-8	Angles	2.0
1-9	Triangles	2.0
1-10	Areas and Volumes	5.0
		27.0

Week 2 Physics

	Math Review	3.0
2-1	Matter and Electron Theory	2.0
2-2	Force and Pressure	2.0
2-3	Pascal's Law	2.0
2-4	Mechanics of Gases	4.0
2-5	Mechanics of Heat	4.0
2-6	Introduction to Diaphragm and Fluid Type Instruments	2.0
2-7	Force and Motion	2.0
2-8	Work and Power	2.0
2-9	Principles of Machines	2.0
2-10	Introduction to Gears	1.0
2-11	Introduction to Gyro Instruments	1.0
		27.0

Basic Electricity

3-1	Introduction to Static Electricity	2.0
3-2	Introduction to Dynamic Electricity	2.0
3-3	Introduction to Ohm's Law and the Rheostat	2.0
3-4	Introduction to Series Circuits	3.0
3-5	Introduction to Parallel Circuits	3.0
3-6	Introduction to Magnetic Theory & Electromagnetism	3.0
3-7	Introduction to Electrical Components	4.0
3-8	Introduction to Safety Devices and Controls	4.0
	Voltage Regulators	
	Reverse Current Relays	
	Circuit Breakers	
3-9	Introduction to Basic Aircraft Electrical Systems	3.0
3-10	The Simpson Multimeter	1.0
		27.0

Week 4 Aerodynamics/Weight & Balance/Instruments

4-1	Introduction to Aircraft	6.0
4-2	Fundamental Rotation and Stresses	2.5
4-3	Aircraft Controls & Systems	3.5
4-4	Atmospheric Effects on Aircraft	1.5
4-5	Introduction to Aerodynamics	4.5
4-6	Rotary Wing Aerodynamics	3.0
4-7	Introduction to Weight & Balance	6.0
		27.0

Week 5 Hardware & Handtools

5-1	Introduction to Hardware & Materials	4.0
5-2	Introduction to Common Handtools	6.5
5-3	Nuts, Bolts, Screws, Fasteners and Special Aircraft Hardware	6.5
5-4	Saftey Devices & Safety Wiring Practical	10.0
		27.0

Week 6 Publications

6-1	Introduction to the Naval Aeronautical Publication Index, 01, 02 and 03 Series of Publications	4.0
6-2	Introduction to the Federal Supply System	4.0
6-3	Bulletins and Changes (Navy)	1.0
6-4	CG ATN, ATO, AMB, and AMC's	1.0
6-5	CG Directives, Publications, and Reports Index - CG-236	1.0
6-6	Flight Record Form CG-4377	1.5
6-7	UR Form, CG-4010	1.0
6-8	Aircraft Records	6.0
6-9	Aircraft Material Stocking List, CG-298	1.5
6-10	Introduction to Air Force Technical Order System	3.0
6-11	Introduction to Coast Guard Technical Order System	1.0
	Practical	2.0
		27.0

PHASE II (Fixed Wing Aircraft)

Week 7 Reciprocating Engines (General)

7-1	Introduction to Power Plants	2.0
7-2	Radial Engine Breakdown	1.0
7-3	Principals of Engine Operation	4.0
7-4	Cylinders, Valves, and Valve Operating Mech.	3.0

Week 7 Reciprocating Engines (Continued)

7-5	Power Transmission Mechanisms	2.0
7-6	Superchargers	2.0
7-7	Cooling and Exhaust System	1.0
7-8	Introduction to Lubrication System	2.0
7-9	Introduction to Aviation Lubricants	2.0
7-10	Introduction to Carburetion	8.0
		27.0

Week 8 Fuels & Ignition

8-1	Aviation Fuels	1.5
8-2	Introduction to Aviation Fluids	1.0
8-3	Introduction to Aircraft Fuel Systems	1.5
8-4	Fuel - Air Ratios	.5
8-5	Introduction to Reciprocating Engine Ignition Sys.	1.0
8-6	Types of Magnetos	1.0
8-7	Circuits & Components of the S9LU Mag.	2.0
8-8	Mechanical Operation of the S9LU Mag.	1.0
8-9	Electrical Operation of the S9LU Mag.	2.0
8-10	Description & Operation of the Induction Vib.	1.0
8-11	Introduction to Spark Plugs	1.0
8-12	Timing the S9LU Magneto (Practical)	13.5
		27.0

Week 9 Hydraulics

9-1	Basic Principle and Theory of Hydraulics	3.0
9-2	Operation of a Basic Aircraft Hydraulics System	.5
9-3	Hydraulic Sealing Devices and Hydraulic Fluids	1.0
9-4	HU-16E Hydraulic System (General)	3.0

Week 9 Hydraulics (Continued)

9-5	HU-16E Main Hydraulic System	5.0
9-6	HU-16E Sub. System	5.0
9-7	HU-16E Hand Pump System	3.0
9-8	Shock Struts	1.0
9-9	The Nose Wheel Shimmy Damper	1.0
9-10	The Variable Delivery Pump	3.0
9-11	The Independent Brake Master Cylinder	.5
9-12	The Disc Type Brake	1.0
		27.0

Week 10 Propellers

10-1	Introduction to Propeller Theory & Types	4.0
10-2	Introduction to the 43D50 Prop.	1.0
10-3	Introduction to the 43D50 Prop. Blade Assy.	1.0
10-4	Introduction to the 43D50 Hub Assy.	1.0
10-5	Introduction to the 43D50 Oil Trans. Housing Assy.	1.0
10-6	Introduction to the 43D50 Prop. Dome Assy.	2.0
10-7	Introduction to the Low Pitch Stop Lever Assy.	1.0
10-8	Introduction to the Control Slip Ring Assy. Including the Brush Pad Bracket Assy.	1.0
10-9	Introduction to the Double-Acting Gov. Assy.	1.0
10-10	Introduction to the StepMotor Electric Head Assy.	2.0
10-11	Introduction to the Integral Oil Control Pump Housing	3.0
10-12	Introduction to the Aux. Oil Supply System	1.0
10-13	Introduction to the Prop Electrical Circuit	2.0
10-14	Procedures for Propeller Servicing	1.0
10-15	Introduction to the 43D50 Prop Deicing System	1.0
10-16	Prop. Removal & Installation (Practical)	4.0
		27.0

Week 11 Line Safety & Inspections

11-1	Introduction to Tow Vehicles	1.0
11-2	Introduction to Mobile Elect. Power Plants	2.0
11-3	High & Low Pressure Air, Uses & Characteristics	.5
11-4	Safety in Maintenance	2.0
11-5	Line Safety	2.0
11-6	Introduction to Maintenance Stands & Equipment	.5
11-7	Aircraft Servicing & Ground Handling	2.0
11-8	Introduction to Periodic Inspection	2.0
11-9	Introduction to the HU-16E Work Card System	1.5
11-10	Introduction to Phased Inspection	1.0
11-11	Introduction to Aircraft Corrosion	2.0
11-12	Periodic Inspection, Practical Application	10.5
		27.0

Week 12 Starts, Stops, & Runups

12-1	Aux. Power Plant	2.0
12-2	Introduction to Start & Stop the HU-16E Engine	2.0
12-3	Operational Runup of HU16E	4.5
12-4	Practical Application	18.5
		27.0

Week 13 Troubleshooting

13-1	Introduction to Trouble Shooting	1.0
13-2	Universal Prop. Protractor	.5
13-3	Introduction to the Dial Indicator	.5
13-4	Introduction to the Piston Position Indicator (Time Rite)	1.0
13-5	Introduction to the Magneto Timing Light	1.0
13-6	Introduction to the Cold Cylinder Indicator	1.0
13-7	Introduction to the S-1 Type Diff. Comp. Tester	1.0

Week 13 Trouble Shooting (Continued)

13-8	Introduction to the High Volt. Insulation Tester	1.0
13-9	Trouble Shooting Aircraft Systems	1.0
13-10	Trouble Shooting the R-1820-76 Engine	3.0
13-11	Line Maintenance of HU-16 Engine	1.5
13-12	Practical Application	14.5
		27.0

PHASE III (Rotary Wing Aircraft)

Week 14 Intro to the HH52A Helicopter

14-1	Development & Theory of Rotary Wing Flight	3.0
14-2	HH52A Airframe	2.0
14-3	HH52A Electrical System	4.0
14-4	HH52A Fuel System	4.0
14-5	HH52A Gear Boxes and Drive Shafts	5.0
14-6	HH52A Rotor Head and Blades	6.0
14-7	HH52A Flight Control Systems	3.0
		27.0

Week 15 Intro to the HH52A Helicopter (Continued)

15-1	HH52A Hydraulic System	6.5
15-2	HH52A Landing Gear System	6.5
15-3	HH52A Heater System	3.0
15-4	HH52A Hoist System	2.0
15-5	HH52A Fire Detector & Extinguishing Systems	2.5
15-6	Review of Torquing Procedures, Safety Wiring and Hardware & Publications	6.5
		27.0

Week 16 Intro to the T-58 Engine

16-1	Jet Engine Theory	4.0
16-2	T-58 Engine	2.0
16-3	Compressor & Accessory Section of the T-58 Engine	3.0

Week 16 Intro to the T-58 Engine

	Combustion Section of the T-58 Engine	1.0
16-5	Gas Generator Section of the T-58 Engine	2.0
16-6	Power Turbine Section of the T-58 Engine	1.0
16-7	Airflow of the T-58 Engine	2.0
16-8	Lubrication System of the T-58 Engine	2.0
16-9	Fuel System of the T-58 Engine	6.0
16-10	Electrical and Stator Vane Actuating Systems of the T-58 Engine	3.0
16-11	Introduction to HH52 Corrosion Control	1.0
		27.0

Week 17 Intro to the T-58 Engine Practical

17-1	Jet Engine Preservation	2.0
17-2	T-58 Engine Removal	1.0
17-3	Preparation of the T-58 Engine for Shipment	1.0
17-4	Removal of the T-58 Engine from the Shipping Container	1.0
17-5	T-58 Engine Inspection Procedures	2.0
17-6	T-58 Engine Accessory Removal	6.0
17-7	T-58 Engine Power Turbine Removal	14.0
17-8	T-58 Engine Gas Generator Turbine Removal	- -
17-9	T-58 Engine Combustion Section Removal and Compressor Section Splitting	
		27.0

Week 18 T-58 Practical (Continued)

18-1	Installation of Compressor Stator & Combustion Section	5.0
18-2	Installation of Gas Generator & Power Turbine Sections	5.0
18-3	Installation of Accessories, Lines, Leads, and Fittings	6.0
18-4	Installation of T-58 Ready Engine Kit Components	5.0
18-5	Introduction to Removal of the HH52A Main Rotor Head Assy.	1.0
18-6	Removal of Rotor Head & Main Transmission of the HH52A	5.0
		27.0

Week 19 HH52A Practical

19-1	Maintenance of the HH52A Main Rotor Head & Gearbox Assemblies (2 Hours Class, 10 Hours Practical)	12.0
19-2	Installation of the Main Rotor Head & Star Assembly	3.0
19-3	Installation of Main Gear Box Quick Change Unit Practical	12.0
		27.0

Week 20 HH52A Line Servicing & Maintenance

20-1	Engine Installation & Depreservation	1.5
	Engine Installation Practical	5.5
20-2	Preflight & Servicing Requirements for the HH52A	2.0
	Preflight Practical	4.0
20-3	Rescue Hoist & Platform Recovery Procedures	2.0
	Rescue Hoist Operational Check Out	2.0
	Aircraft Hoisting Exercise (Live Hoisting Under Supervision)	3.0
20-4	Aircraft Ground Handling	1.5
	Aircraft Ground Handling Practical	2.0
20-5	Aircraft Taxi Signals	1.0
	Aircraft Taxi Signals Practical	2.5
		27.0

PHASE I (AIRMAN PREPARATORY CONTINUED)

Week 21 Military - CG-333 - Survival

21-1	Introduction to USCG Warrant Officer Specialties & Uniform Identification	1.0
21-2	Air Station Organization	2.5
21-3	Introduction to Air Station Watch Lists	1.5
21-4	Introduction to Shipboard Armament	.5
21-5	NBC Warfare	1.5
21-6	Survival	4.0
21-7	Survival Equipment	8.0
	Practical	2.0
21-8	Flight Physiology & Water Survival Training	3.0
	Practical	3.0
	(Conducted at Navy Norfolk on a facility available basis)	
		27.0

WEEK 1

TITLE

Introduction to Mathematics

TOPIC OBJECTIVE

To familiarize the student with general mathematics, fractions, decimals, percentages, positive and negative numbers, ratio and proportion, introduction to angles, area's and volumes, and triangles. The student will be able to:

(a) Name and explain the mathematical terms used.

(b) Correctly solve problems utilizing the terms and formulas discussed.

WEEK 2

TITLE

Introduction to physics

TOPIC OBJECTIVE

To familiarize the student with matter, electron theory, force and pressure, Pascal's Law, heat, force and motion, work and power, principles of machines, and gears. The student will be able to:

(a) Define the physics terms discussed in this week.

(b) List and explain the laws dealing with physics.

(c) Solve problems working with formulas used in physics.

WEEK 3

TITLE

Introduction to Basic Electricity

TOPIC OBJECTIVE

To introduce the student to the theory of basic electricity, electrical components, safety devices, basic DC aircraft electrical systems and the Simpson Multimeter. The student will be able to:

(a) Define and explain the following:

  (1) Static Electricity.

  (2) Dynamic Electricity.

  (3) Ohm's Law and the Rheostat.

  (4) Series Circuit.

  (5) Parallel Circuits.

  (6) Magnetic Theory and Electromagnetism.

  (7) Electrical Components.

  (8) Safety Devices and Controls.

  (9) Basic DC Aircraft Electrical System.

  (10) Simpson Multimeter.

(b) Describe safety precautions to be observed when dealing with electricity and electrical components.

(c) Solve electrical problems utilizing the Ohm's Law formula.

(d) Explain current flow and resistance.

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WEEK 4

TITLE

Introduction to Aerodynamics

TOPIC OBJECTIVE

To familiarize the student with types and classes of aircraft, rotational axis and stresses encountered in flight, aircraft control systems, atmospheric effects on aircraft, aerodynamics, rotary wing aerodynamics, weight and balance, electrical and remote reading instruments, and navigation instruments. The student will be able to:

(a) Explain safety precautions outlined in CG ATN-4-71 to be observed when maintenance is performed on an aircraft control system.

(b) Define the terms, laws, and principles utilized in aerodynamics.

(c) Solve problems in weight and balance utilizing the terms, formulas and load adjuster.

Describe the purpose of electrical and navigation instruments.

WEEK 5

TITLE

Hardware and Handtools

TOPIC OBJECTIVE

To familiarize the student with the selection and proper use of the more common hardware and handtools associated with aviation, including certain special tools, ie. micrometers, torque wrenches etc. Also introduces him to the correct safety procedures associated with hardware and handtools. The student will be able to:

(a) List and explain properties of metals, metal characteristics, forms, shapes and alloys utilized.

(b) List the two types of tubing used in aircraft, explain the color coding used to identify tubine systems and list and explain installation procedures and precautions.

(c) Identify, describe and list uses of selected common handtools including Vernier Micrometers and dial indicators.

Identify, describe and list uses of the more common hardware including control cables, turnbuckles, control rods, and rod ends. Describe the use of a tensiometer.

(e) Identify, explain uses of, and safety precautions involved with different safety wire and cotter pins. Satisfactorly demonstrate his knowledge and ability by completing a sample safety wire and cotter pin board in one hours time.

WEEK 6

TITLE

Publications

TOPIC OBJECTIVE

To familiarize the student with the various forms, publications, logs and records associated with Coast Guard Aviation. The student will be able to:

(a) Name the five parts and describe the purpose of the Naval Aeronautical Publications Index. Explain the Navy publications numbering system. Explain the difference between a manual and a letter type publication. Describe the purpose of the maintenance manual and the illustrated parts breakdown. Explain the sequence of events for locating a manual or letter type publication.

(b) Name and describe the three parts of a federal stock number. Identify by name the CRL1N, CRL2N, and NMDL. Explain the sequence of events for determining the FSN, unit of issue, description, and price of an item beginning with a part number.

(c) Name and explain the purpose of and the three catagories of changes and bulletins (Navy).

(d) Name and explain the purpose of AMB's, AMC's, ATN's and ATO's.

(e) Name and describe the purpose of the directives, Publications and Reports Index, CG-236. Describe the security classification system, its purpose and identifing code, and the method of numbering and filing directives.

(f) Identify by number the aircraft flight record form, CG-4377 and explain the purpose of each part, and the method of numbering and filing the aircraft flight record.

(g) Identify by number and explain the purpose, importance, and the desired results of the unsatisfactory report form, CG-4010.

(h) Name, describe, and explain the purpose of the aircraft log and record.

(i) Identify and explain the purpose of OPNAV 4790/35, Maintenance Instruction.

(j) Identify and explain the objectives of the aircraft material stocking list. List and describe the three categories of material as listed therein.

WEEK 6 (Cont'd)

(k) Name and explain NI&RT and list of applicable publication systems. Describe the AFTO system and its purpose. Explain the AFTO numbering system.

(l) Describe the Coast Guard technical order system and its purpose.

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WEEK 9

Title

Hydraulics

Topic Objective

To familiarize the student with a basic understanding of a hydraulic system including components, types of fluid, operation and minor maintenance. At the completion of this week the student will be able to:

(a) Name and describe the advantages and disadvantages of a hydraulic system.

(b) Name and describe the essential components in a practical hydraulic system (hydraulic jack), and explain how force is transmitted from input to output.

(c) Solve correctly simple mathematical problems illustrating the mechanical advantage achieved in hydraulics.

(d) Explain the purpose of each component in a basic hydraulic system.

(e) Name and describe the various sealing devices used in aircraft hydraulic systems.

(f) Explain the application and purpose of the different design hydraulic sealing devices.

(g) Name and describe the types of hydraulic fluids and their characteristics.

(h) Name and describe the types of hydraulic systems used in the HU-16E.

(i) Name and describe the components that are common to both power operated systems.

(j) List the pressure limits and volumes of the components that are common to both power operated systems.

(k) Perform minor maintenance on the system.

WEEK 10

Title

Propellers

Topic Objective

To familiarize the student with basic propeller types, propeller theory, operation, removal, installation, servicing and safety. The student will be able to:

(a) Explain the forces created by a rotating propeller, how the propeller produces thrust, and safety rules to be observed in the area of propeller rotational plane.

(b) Explain the meaning of various letters and numbers in the propeller hub assembly model designation and identify the seven (7) components that make up the 43D50 propeller.

(c) List and describe the major parts of the propeller hub assembly; state the location, purpose and the flow of oil through the hub. explain the proper procedure for securing and locking the hub assembly to the propeller shaft.

(d) List and describe the major parts of the propeller blade and state the location of each. Explain the purpose of each major part of the assembly.

(e) List and describe the purpose, major parts, location and functions of the dome assembly.

(f) State the location and purpose of the slip ring and brush pad and how they are mounted.

(g) State the location, purpose and operation of the governor stepmotor head and integral oil system.

(h) State the purpose of the aux oil system. List and describe the components and operation of the aux oil system.

(i) List and describe the major components of the propeller electrical circuit and explain its operation.

(j) List the proper oil acceptable for use in the 43D50 propeller and correct procedures for servicing.

(k) Name and identify components of the deicing system and explain its operation.

(l) Explain the proper procedure for removal and installation of the 43D50 propeller assembly.

WEEK 11

Title

Line Safety and Inspections

Topic Objective

To familiarize the student with general ground support equipment, operating procedures and safety precautions. The student will be introduced to:

(a) General ground support equipment, including demonstrations.

(b) Aircraft servicing and ground handling.

(c) Inspection methods and procedures.

(d) Aircraft corrosion and corrosion control practices.

(e) HU-16E periodic inspections.

WEEK 12

Title

Starts, Stops and Run-ups

Topic Objective

To familiarize the student with the correct procedures for inspection and operation of the APU and the R1820 Engine. The student will be able to:

(a) Demonstrate the purpose, application and use of the V-32D-2 APU.

(b) Perform pre-flight and post-flight inspections of the HU-16E aircraft.

(c) Perform starts, run-ups and stops of the APU and Main engines of the HU-16E, in compliance with the NATOPS Manual 01-85-AC1 and the Standardization Manual, CG-372.

WEEK 13

Title

Trouble Shooting

Topic Objective

To familiarize the student with the correct methods, tools and procedures for effective trouble shooting and minor discrepancy repairs. The student will be able to:

(a) Explain the reason for trouble shooting, where to locate information concerning the trouble and the use of the four step and V.I.C.E. method used in trouble shooting.

(b) Demonstrate the ability to correctly use and the purpose of the following items:

universal propeller protractor
dial indicator
piston position indicator
magneto timing light
cold cylinder indicator
S-1 type differential compression tester
high voltage tester

(c) Demonstrate the ability to make idle mixture and idle speed adjustments; fuel and oil adjustments; remove, inspect and install spark plugs; clean reciprocating engines.

MODIFICATIONS

Pages 24-29 of this publication has (have) been deleted in adapting this material for inclusion in the "Trial Implementation of a Model System to Provide Military Curriculum Materials for Use in Vocational and Technical Education." Deleted material involves extensive use of military forms, procedures, systems, etc. and was not considered appropriate for use in vocational and technical education.

APPENDICES

SECTION A EQUIPMENT AND FURNITURE REQUIREMENTS PAGE A1

SECTION B TRAINING AIDS AND DEVICES PAGE B1 THRU B2

SECTION C PUBLICATIONS USED AS TEXTS OR REFERENCES PAGE C1 THRU C6

SECTION D SPACE REQUIREMENTS PAGE D1

SECTION E STAFFING REQUIREMENT BY GRADE AND RATE WITH ORGANIZATION PAGE E1 THRU E3

Number of an item	
1	Hanger air compressors, ingersol rand
1	Bandsaw, do-all
65	Bookcase, section, metal
17	Bookcase, base, metal
6	Buffer, floor
1	Cabinet, duplicator
7	Cabinet, file, metal, letter size
25	Cabinet, storage
1	Calculator, Victor 1800
1	Calculator, Friden
23	Chairs, swivel, desk
159	Chairs, student
1	Chalk & bulletin board
1	Charger, battery
1	Cleaner, steam
8	Coat racks
1	Floor Jack
1	Cutter, Paper
7	Desk, metal, double pedestal
13	Desk, metal, single, pedestal
3	Drill, electric, hand
1	Drill, Pneumatic, hand
1	Drill press
6	Fan, pedestal
1	S-16E Cabinet, 8 X 5 card
2	Grinder, bench
1	Lathe, metal turning
13	Lockers, metal single
1	Machine, duplicating, ditto
1	Reel, air hose
1	Sander, belt & disc
1	Saw, electric circular
1	Saw, recipricating
1	Saw, miter box
1	Refrigerator
1	Sander, orbital
1	Saw, horizontal band
8	Stand, office machine
4	Stools, draftsman
114	Table, student
2	Tap & die set
4	Typewriter, office, Electric
1	Vacuum cleaner
2	Water cooler
1	Welder, electric, 1 ea Burner/welder oxy/acetylene
2	Couches (Student lounge)
4	Lounge chairs (Student Lounge)

TRAINING AIDES AND DEVICES

Number of each item	
2	HU16E Aircraft
3	HH52A Helicopter (1 operational)
1	Applicator, Water
1	Applicator, rust lick
1	Auxiliary Power Unit
2	Borescopes
5	Chalk Boards
8	Carts, 3 Shelves with castors
2	Compression Tester
1	Copy maker, Thermal image
1	Compressor, air, Cornelius
1	Electronic Stensil Cutter
1	Gantry, 3 Ton Capacity
350	16mm movies
1	Hydraulic Power Unit
1	Grease Gun, Lincoln Pneumatic
1	Hoist, electric
1	Indicator, dial
3	Jack, AC 3 Ton
1	Jet Cal. Tester
1	Kit, T58, special tools
3	Multimeters
1	Micrometer, set
1	Micrometer, depth
1	Power supply,+ Portable, 28 VDC
1	Preservation unit, engine
2	Projector, opaque
5	Projector, 16mm
1	Projector, Sound on Slide
7	Projector, overhead
6	Protractor, propellop
1	Puller Kit, mechanical, bearing/bushing
1	Rectifier, 28 VDC
2	Screen, slide & movie, portable
1	S.V.A. Ind, Kit T58
1	Tester, Delta P
1	Tester, Torque Wrench
1	Tool Box, Roll Around
1	Tractor, Towing
1	Vacublast machine
6	Vise, bench
8	Wrench, torque
2	T58 engines
2	1820 QEC's
1	HU16E Hydraulic system mock-up
1	HU16E Fuel System mock-up

1	HU16E Propeller system mock-up
1	HU16E Propeller cut away
3	HH52A Maintenance stands
2	Universal tow bars
1	HU16E Heater system mock-up
1	HH52A Heater system mock-up
1	HU16E Electrical system mock-up
1	HH52A Electrical System mock-up
1	HU16E Engine instruement system mock-up
1	HU16E Auto Pilot system mock-up
1	HU16E Fuel Indication system mock-up
1	Radial engine ignition siming & valve mock-up
3	T-58 Engine carts
1	T-58 Engine cans
1	1820 Engine cut-away
1	HH52A Transmission & rotor head cut-away
3	HH52A Rotor blades & stand
2	HU16E Oil Tank cut-away
1	43D50 Propeller & Stand
1	Propeller bench
1	Hydraulic testing unit
ALL	43D50 Propeller special tools
ALL	T-58 Engine special tools
ALL	HH52A special tools
2	T-58 Engine nose stands
2	T-58 Engine power turbin stands
1	Waukeshaw portable power unit
2	Aero stands
4	HU16E Maintenance stands
ALL	1820 special tools

PUBLICATIONS USED AS TEXTS OR REFERENCES

WEEK 1 - A. Math Study Guide CNATT-P-630
B. Basic Mathematics, Vol. 1

WEEK 2 - A. Aviation Physics Study Guide and Workbook, CNATT-P-40
B. Powerplants for Aerospace Vehicles, CH-10, page 200-201 (Third Edition)
C. Basic Electricity, NAVPERS 10086A
D. Airman Manual NAVPERS 10307A
E. Aviation Electricians Mate 3&2 NAVPERS 10348-B
F. The New American Machinist's Handbook, by Rupert Legrand

WEEK 3 - A. Basic Electricity, NAVPERS 10086A
B. Aviation Physics Workbook CNATT-P-40
C. USCG pamphlet no. 210
D. AE 3&2 Manual NAVPERS 10348-B
E. Powerplants for Aerospace Vehicles

WEEK 4 - A. NIT Basic Science, chapter 8 (Third Edition)
B. BUWEPS INST 13100.7
C. Airman Manual NAVPERS 10307A
D. CG ATN 4-71
E. Sikorsky Theory of Flight
F. Helicopter History and Aerodynamics Manual NAVAIR 00-80T-88
G. DD form 365 A, B, C, & F
H. Aviation Electricians Mate 3&2 NAVPERS 10348-B

WEEK 5 - A. FAA Airframe and Powerplant Mechanics Manual (AC65-15)
B. Airman Manual NAVPERS 10307
C. AMS 3&2 NAVAER 10308
D. NIT Basic Science Aerospace Vehicles (Third Edition)
E. Military Standards MS 33540

WEEK 6 - A. Maintenance Instructions Manual NAVWEPS 01-85AB-2
B. Illustrated Parts Breakdown NAVWEPS 01-85AB-4
C. CRL1N, CRL2N, NMDL, C0006
D. ATN 5-60
E. CG-199-1, CG-236
F. Commandant Instruction 13090.2A
G. ATN 5-70
H. Commandant Instruction 13090.1A
I. OPNAVINST 4790.2, Vol. II
J. CG-298 A/C Material Stocking List
K. AFTO 00-5-1, 00-5-2, NI&RT 0-1-01

PUBLICATIONS USED AS TEXTS OR REFERENCES

WEEK - 7 A. NAVPERS #10343A
B. FAA Powerplant Manual AC65-12
C. NIT Powerplants for Aerospace Vehicles
D. NAVPERS #10342A
E. NAVWEPS #00-80T-42
F. NAVAIR 02A-35GH-502
G. HMI R1820-76 Engine
H. NAVWEPS 03-108A-101 PD12K-10 Carb Manual

WEEK - 8 A. Powerplants for Aerospace vehicles 3rd Ed Nit
B. NAVPERS 10342
C. Aviation fuels NAVAER 06-5-501
D. NAVAIR 01-85AB-2 HU16-E E&M Manual
E. NAVPERS 10335A
F. FAA Airframe and Powerplants Manual AC65-12 CH.4
G. COMDT INST 13000 series, GREB3B
H. Time-rite piston position instruction book
I. NAVAIR 02A-35GH-502

WEEK - 9 A. NAVPERS # 10310A
B. Basic science for Aerospace Vehicles
C. NAVWEPS 01-85AC-1, NW01-85AB-2

WEEK -10 A. Powerplants for Aerospace Vehicles 3rd ED. N.I.T.
B. Hamilton Standard's Prop to Pilot
C. NW 03-20CC-38
D. NW 03-20CC-39
E. NW 03-20CC-40
F. NA 01-85AB-2

WEEK -11 A. NAVPERS 10342-A (ADR 3&2)
B. NAVAIR 19-45-10
C. NAVPERS 10307-C (AIRMAN)
D. USCG Institute course for AD2
E. NAVWEPS 00-80T-96
F. NAVPERS 1037-B
G. NA 01-85AB-2
H. NA01-85AC-1
I. ATN 1-71 & 1-71D
J. Maintenance & repair of aero space
K. Vehicles N.I.T.
L. HU16 Aircraft Model Bulletin 145
M. ATN 4-71
N. NA 01-1A-509
O. ATN 1-68

WEEK -12 A. NA 01-AC-1
B. NA 01-AB-2
C. NA 01-85AC-1

PUBLICATIONS USED AS TEXTS OR REFERENCES

	D.	NA 01-85AB-2
	E.	CG 372
	F.	NA 02A-35GH-502
WEEK -13	A.	NAVAIR 01-85AB-2
	B.	NAVWEPS 10085-A
	C.	NAVAIR 02A-35GH-502
	D.	CG 372
	E.	NAVWEPS 01-1A-506
WEEK -14	A.	NW 00-80T-88
	B.	Sikorsky Theory of Flight
	C.	CGTO 1H-52A-1
	D.	CGTO 1H-52A-2
	E.	Sikorsky Service School Manual
WEEK -15	A.	CGTO 1H-52A-1, HH52A Flight Handbook
	B.	CGTO 1H-52A-2, HH52A Maintenance Manual
	C.	CGTO 1H-52A-4, HH52A I.P.B.
	D.	NA 02B-105AHB-2
WEEK -16	A.	Powerplants for Aerospace vehicles 3rd ED (NIT)
	B.	Jet Aircraft Power Systems 3rd ED (NIT)
	C.	T-58 Engine Training Guide
	D.	NA 02B-105AHB-2
	E.	T58-G#-88 Intermediate Maintenance Manual
WEEK -17	A.	NA02B-105AHB-2
	B.	NA 15-02-500
	C.	CGTO 1H-52A-2
	D.	CGTO 1H-52A-6
	E.	CGTO T58-8B-6EM Series work cards
	F.	CGTO 1H-52A-6FI work cards
	G.	ATN 1-71
WEEK -18	A.	CGTO T58-8B-6EM
	B.	NA 02B-105AHB-2
	C.	CGTO 1H-52A-2
WEEK -19	A.	CGTO 1H-52A-2
WEEK -20	A.	CGTO 1H-52A-2
	B.	NA 0213-105AH13-2
	C.	CGTO 1H-52A-6
	D.	ATN NO. 1-71
	E.	HH52A Bulletin No. 40
	F.	CGTO 1H-52A-1
	G.	NAVPERS 10307-B
WEEK -21	A.	USCG Pamphlet No. 159
	B.	Coast Guardsman Manual
	C.	CG 333
	D.	CG 294
	E.	CG Pahphlet No. 108, 109

PUBLICATIONS USED AS TEXTS OR REFERENCES

F. NAVWEPS 00-80T-56, NAVAIR 13-1-6.2
G. NAVPERS 10087, NAVAIR 00-80-T-52
H. CG Pamphlet No. 458

SPACE REQUIREMENTS

Office Spaces	Space Required
Chief, AD Training Branch Office	151 sq ft
Asst Chief, AD Training Branch Office	144 sq ft
Testing and Files Office	300 sq ft
Instructors Offices	1475 sq ft
Conference Room	475 sq ft
Student Lounge	448 sq ft
Classrooms for AD(A) School-3 each with minimum of	475 sq ft
HU-16E (C) School Classroom	1000 sq ft
HH-52A (C) School Classroom	875 sq ft
T-58 Engine and Propeller Shop	2000 sq ft
Shop (Training Aids Maintenance)	616 sq ft
Training Aids Storage	744 sq ft
Special Tool Storage	250 sq ft
Store Room	150 sq ft
Head, Student's and Staff	322 sq ft
Furnace Room	112 sq ft
Total Floor Space including Hangar	25,690 sq ft

40

MODIFICATIONS

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41

DEPARTMENT OF TRANSPORTATION

COAST GUARD

Aviation Machinist's Mate School Class - A

2-5

Mathematics/Physics/Electrical

Workbook

Aviation Training Division
USCG-AR&SC-Elizabeth City. N. C.

?
I AM MIXING SOME WHOLE NUMBERS AND FRACTIONS --- FOR MORE ACCURACY!

Whole Numbers and Fractions

In these two lessons, whole numbers and fractions are reviewed. Whole numbers - or integers - are the familiar numbers used in counting. As a matter of fact, counting is about the only operation for which whole numbers are completely satisfactory. If any kind of a measurement is to be made, whether it be of length, height, weight, or volume, it very seldom happens that the result can be expressed accurately as a whole number. To take care of this inaccuracy, fractions and decimals are used. Fractions should be regarded as an extension of the system of whole numbers, the latter being a special case of fractions with 1 as denominator. The operations of addition, subtraction, multiplication, and division as applied to fractions are here. Finally, the reciprocal of a fraction, which is related in a special way to the given fraction, is defined.

I. Definitions

Examples

A. Addition

1. Addends - The numbers that are to be added
2. Sum - The result of addition

Add

$$\begin{array}{r l} \left.\begin{array}{r} 7 \\ 6 \\ \underline{1} \end{array}\right\} & \text{Addends} \\ 14 & \text{Sum} \end{array}$$

B. Subtraction

1. Minuend - The number from which another is to be subtracted
2. Subtrahend - The number that is to be subtracted
3. Remainder (Difference) - That which remains after subtraction

Subtract

$$\begin{array}{r l} 7 & \text{Minuend} \\ \underline{6} & \text{Subtrahend} \\ 1 & \text{Remainder} \end{array}$$

C. Multiplication

1. Multiplicand - The number that is to be multiplied
2. Multiplier - The multiplying number
3. Product - The result of multiplication

Multiply

$$\begin{array}{r l} 7 & \text{Multiplicand} \\ \underline{6} & \text{Multiplier} \\ 42 & \text{Product} \end{array}$$

D. Division

1. Divisor - The number that is divided into another
2. Dividend - The number that is being divided
3. Quotient - The result of division

Divide

$$\begin{array}{r r l} & 6 & \text{Quotient} \\ \text{Divisor} \quad 6 & \overline{)\,36} & \text{Dividend} \end{array}$$

II. Fractions

A. Definition

$\frac{1}{7}$, $\frac{7}{4}$, 11/3

1. Numerator
2. Denominator

$$\begin{array}{l l} 1 & \text{Numerator} \\ \hline 4 & \text{Denominator} \end{array}$$

Examples

B. Types
 1. Proper - The numerator is smaller than the denominator. (1) 7/13 Proper Fraction

 2. Improper - The numerator is larger than the denominator. (2) 14/6; 3/3 Improper Fractions

 3. Mixed Numbers - A whole number and a fraction. (3) 2 1/7 Mixed Number

III. To change mixed numbers to improper fractions:

A. Multiply the whole number by the denominator of the fraction.

B. Add the product to the numerator. $2\ 1/7 = \frac{(2 \times 7) + 1}{7} = \frac{15}{7}$

C. Place the sum over the denominator of the fraction.

IV. To change improper fractions to mixed numbers:

A. Divide the denominator into the numerator. The quotient is the whole number.

B. Place the remainder over the denominator. $\frac{17}{3} = 3\overline{)17} = 5\ 2/3$

V. Reducing fractions:

Divide both the numerator and the denominator by the same number.

$$\frac{2}{4} = \frac{2 \div 2}{4 \div 2} = \frac{1}{2}$$

VI. Solving fractions:

A. Addition
 1. Fractions with common denominators are added as follows:
  a. Add numerators. $\frac{1}{2}+\frac{5}{2}+\frac{3}{2} = \frac{9}{2} = 4\ 1/2$
  b. Keep common denominator. $\frac{1}{3} + \frac{1}{3} = \frac{2}{3}$

 2. To add fractions with unlike denominators, proceed as follows:
  a. Change fractions to common denominators.
  b. Add numerators.
  c. Keep common denominator. $\frac{1}{2} + \frac{3}{4} + \frac{2}{8} =$

  NOTES: $\frac{4}{8} + \frac{6}{8} + \frac{2}{8} = \frac{12}{8} = 1\ 1/2$

3. Mixed numbers may be added in the following manner:
   a. Change fractions to common denominators.
   b. Add fractions.
   c. Add whole numbers.
   d. If fraction is improper, change to a mixed number.
   e. Combine whole numbers.

Examples

$$\begin{array}{r} 2\ 2/3 = 2\ 4/6 \\ \underline{4\ 5/6 = 4\ 5/6} \\ 6\ 9/6 = 7\ 1/2 \end{array}$$

B. Subtraction

1. To subtract fractions having a common denominator:
   a. Subtract numerators.
   b. Keep common denominator.

$$\begin{array}{l} \frac{5}{8} \\ \frac{3}{8} \\ \frac{2}{8} = \frac{1}{4} \end{array}$$

2. To subtract fractions having unlike denominators, do the following:
   a. Change fractions to common denominators.
   b. Subtract numerators.
   c. Keep common denominator.

$$\begin{array}{r} \frac{3}{4} = \frac{6}{8} \\ \frac{3}{8} = \frac{3}{8} \\ \hline \frac{3}{8} \end{array}$$

3. To subtract mixed numbers, proceed as outlined below.
   a. Change fractions to lowest common denominators.
   b. Subtract fractions.
   c. If subtrahend fraction is larger than minuend fraction, borrow one from the whole number.
   d. Subtract whole numbers.

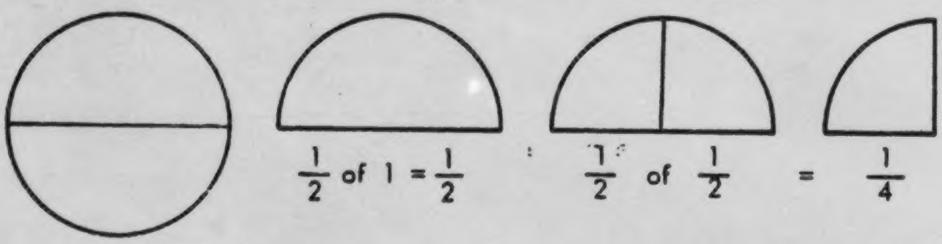
$$\begin{array}{r} 7\ 1/5 = 7\ 2/10 = 6\ 12/10 \\ \underline{4\ 1/2 = 4\ 5/10 = 4\ 5/10} \\ 2\ 7/10 \end{array}$$

NOTES:

Examples

C. Multiplication

1. Common fractions may be multiplied as indicated below:



$\frac{1}{2}$ of $1 = \frac{1}{2}$: $\frac{1}{2}$ of $\frac{1}{2} = \frac{1}{4}$

a. Multiply numerators. $2/3 \times 1/3 = 2/9$

b. Multiply denominators. $1/2 \times 4/1 = 4/2 = 2$

2. Cancellation:
Numbers in the numerator may be cancelled by numbers in the denominator.

$$\frac{2}{3}\times\frac{3}{4}\times\frac{8}{9}=\frac{\overset{1}{\cancel{2}}}{\underset{1}{\cancel{3}}}\times\frac{\overset{1}{\cancel{3}}}{\underset{\underset{1}{\cancel{2}}}{\cancel{4}}}\times\frac{\overset{4}{\cancel{8}}}{9}=\frac{4}{9}$$

3. Mixed numbers are multiplied as follows:
   a. Change to improper fraction.
   b. Proceed as above.

$$3\ 1/3 \times 4\ 1/5 = \frac{\overset{2}{\cancel{10}}}{\underset{1}{\cancel{3}}}\times\frac{\overset{7}{\cancel{21}}}{\underset{1}{\cancel{5}}} = 14$$

D. Division

TO DIVIDE 4 BY 2 IS TO FIND OUT HOW MANY TIMES 2 IS CONTAINED IN 4 AS A FACTOR. LIKEWISE, TO DIVIDE 1/2 BY 1/4 IS TO DETERMINE HOW MANY TIMES 1/4 IS CONTAINED IN 1/2.

1. To divide common fractions, proceed as follows:
   a. Invert the divisor. $\frac{1}{2} \div \frac{1}{4} =$
   b. Proceed as in multiplication. $\frac{1}{2} \times \frac{4}{1} = \frac{4}{2} = 2$

2. The steps in the division of mixed numbers are:
   a. Change to improper fraction.
   b. Proceed as above.

$3\ 1/3 \div 2\ 1/4 = 10/3 \div 9/4 =$
$10/3 \times 4/9 = 40/27 = 1\ 13/27$

Examples

VII. Reciprocals

A. Definition
That number divided into one.

3 reciprocal is $\frac{1}{3}$

$\frac{1}{3}$ reciprocal is $\frac{1}{\frac{1}{3}} = \frac{1}{1} \div \frac{1}{3} =$

$\frac{1}{1} \times \frac{3}{1} = \frac{3}{1} = 3$

B. Use

1. Division
Multiply by reciprocal: $3 \div \frac{1}{2} =$ 3 times the reciprocal of $\frac{1}{2} =$

2. Multiplication
Divide by the reciprocal. $3 \times \frac{2}{1} = 6$

Reference Material

A. Basic Principle

A fraction is unchanged in value if both numerator and denominator are multiplied or divided by the same number.

$$\frac{1}{2} = \frac{1 \times 5}{2 \times 5} = \frac{5}{10} = \frac{5 \times 4}{10 \times 4} = \frac{20}{40} = \frac{20 \div 5}{40 \div 5} = \frac{4 \div 2}{8 \div 2} = \frac{2}{4} = \frac{1}{2}$$

B. Lowest Common Denominator (LCD)

This is the smallest whole number divisible by all the denominators of a set of fractions. For ordinary fractions found in this course, the LCD is found by inspection.

$$\frac{3}{4}, \frac{5}{7}, \frac{1}{2}, \frac{1}{5}$$

The LCD of the above fractions is

4 × 7 × 5 = 140

$$\frac{1}{3}, \frac{1}{2}, \frac{1}{4}$$

The LCD of the above fractions is 12.

C. Addition and Subtraction

To add or subtract fractions, write them in equivalent form with the same LCD, according to the above principle, and add or subtract the numerators, keeping the LCD as denominator.

$$\frac{1}{2} + \frac{3}{5} + \frac{1}{4} = \frac{10}{20} + \frac{12}{20} + \frac{5}{20} = \frac{27}{20} = 1\frac{7}{20}$$

D. Multiplication

To multiply fractions, multiply the numerators together and the denominators together, after performing all possible cancellations and reductions.

$$2\frac{1}{2} \times \frac{1}{10} \times 1\frac{1}{4} \times \frac{2}{3} = \frac{\cancel{5}^{1}}{\underset{1}{\cancel{2}}} \times \frac{1}{\underset{2}{\cancel{10}}} \times \frac{5}{4} \times \frac{\cancel{2}^{1}}{3} = \frac{5}{24}$$

E. Division

To divide a number by a fraction, invert the divisor and multiply.

$$4\frac{2}{3} \div \frac{5}{6} = \frac{14}{\underset{1}{\cancel{3}}} \times \frac{\cancel{6}^{2}}{5} = \frac{28}{5} = 5\frac{3}{5}$$

F. Reciprocals

To find the reciprocal of a number, divide one by that number.

The reciprocal of 4 is $1 \div 4 = \frac{1}{4}$

Work Sheet WHOLE NUMBERS AND FRACTIONS

FILL-IN PROBLEMS

1. When numbers are added, subtracted, multiplied and divided respectively, the results are referred to as the ____________ ____________ ____________ and ______________________

2. If 12 is subtracted from 15, 12 is called the ______________________________ and 15 the ________________________.

3. If 50 is divided by 5, 50 is called the ______________ and 5 the ____________.

4. If 18 is expressed as the product of 6 and 3, the numbers 6 and 3 are called __________________________ of 18.

5. The top number of a fraction is called the ________________ and the bottom number the ____________________.

6. The two types of fractions that are interchangeable are ____________________ and _________ ______________.

7. The fraction 4/7 is an example of a ________________ fraction.

8. Whole numbers can be regarded as fractions with a denominator of ___________.

9. The smallest whole number which is divisible by a set of denominators is called the ______________________.

10. To reduce a fraction, ___________ the numerator and denominator by the same number.

11. A fraction is unchanged in value when both numerator and denominator are ________________ or __________________ by the same number.

12. When fractions with the same denominators are to be added, add the ____________ and keep the same _______________.

13. When fractions with unlike denominators are to be added or subtracted, transform them by giving them a ____________________________.

14. When two fractions are to be multiplied together, reduce and then ____________ the numerators and __________________ the denominators.

15. To divide one fraction by another, ____________ the divisor and ____________.

16. To divide one number by another, multiply by the _____________ of the divisor.

17. If the numerator is the same, the smaller the denominator, the ________________ the fraction.

PROBLEMS

1. In each of these fractions, tell whether both (terms) numerator and denominator are exactly divisible by 2, 3, 6, 8, 10. Then reduce the fractions to their lowest terms:

   (a) $\frac{12}{16}$ __________ (b) $\frac{18}{36}$ __________ (c) $\frac{24}{42}$ __________ (d) $\frac{54}{135}$ ______

   (e) $\frac{128}{224}$ __________

2. Change the following to the simplest form:

   (a) $\frac{27}{6}$ ______ (b) $\frac{14}{35}$ ______ (c) $4\frac{10}{16}$ ______ (d) $\frac{77}{10}$ ______ (e) $\frac{92}{5}$ ____

3. Solve:

   a. 7 2/3 + 9 3/4 + 11 1/2 __________ d. 8 + 7/4 + 8/3 + 7/2 ____________

   b. 9/10 + 7/12 + 5/4 + 2/3 __________ e. 14 3/4 + 30 1/2 + 4 ____________

   c. 12 1/12 + 24 1/24 + 36 1/36 ______ f. 4/5 + 5/6 + 7/10 ______________

4. A golfer drives a ball 253 3/4 yds., 180 7/8 yds., 33 7/8 yds., then putts 5 1/2 yds. and 1 1/5 yds. Find the total number of yards that the ball was played. __________

5. A merchant sold to different customers 4 1/4, 7 2/3, 7 5/8, and 2 1/2 yds. of cloth, respectively. Find the total number of yards sold. __________

6. From the sum of 7 7/8 and 3 3/4 subtract the sum of 2 1/5 and 4 1/2. __________

7. Subtract 5 7/8 from 16 3/4. __________

8. Subtract 27 3/4 from 42 2/3. __________

9. The difference between 7 5/6 and 15 5/12 is ____________.

10. In building a fence, a man used steel posts 6 1/2 feet high. He drove each post 2 1/4 feet into the ground. How much of each post was above the ground? ______

11. A farmer had a field containing 3 11/16 acres. From a neighbor, he purchased enough land to make the field 5 3/4 acres. How much land did he buy? ________

12. A fountain pen and pencil set sells for $4.50. The pen alone sells for 2/3 of the price of the set. What is the cost of the pencil? __________

13. How much will 55 1/2 feet of sash cord cost at 3/4¢ a foot? ___________

14. Solve:

    a. 6 × 2/3 ______________

    b. 5/8 × 4/15 ______________

    c. 3/5 × 2/3 × 5/8 ________

    d. 8 5/8 × 2/3 ______________

    e. 22 × 6 7/8 ______________

    f. 4 2/4 × 5 1/4 × 2 3/4 ________

15. A man drove 220 miles in 6 2/3 hours. What was his average speed in miles per hour? ______________

16. A filling station advertised 6 1/4 gallons of gas for $1.00. What was the exact price per gallon? ______________

17. A druggist advertised soap at 7 3/4 ¢ a cake. At this rate, how much will he receive for 1/2 dozen cakes? ______________

18. Solve:

    a. 5 5/6 ÷ 7/6 ______________

    b. Divide 7/8 by 7/16 ________

    c. Divide 4 1/16 into 15 ______

    d. 9/16 ÷ 8 ______________

    e. 4/5 ÷ 2 7/15 ____________

    f. 4 2/3 ÷ 12 3/5 ______________

    g. 2 1/2 × 7/8 ÷ 2 2/3 ________

    h. 4 1/2 + 2 1/6 - 4 6/7 ________

    i. (4 1/2 ÷ 2) + 6 1/4 __________

19. Give the reciprocal of the following:

    a. 12 ______________

    b. 2 1/2 ____________

    c. 1/6 ______________

    d. $\frac{1}{1/8}$ ______________

    e. 5/4 ______________

    f. 3 1/3 ____________

20. Find the difference between 3 1/3 and its reciprocal. ____________________

21. What is the sum of 2 1/2 and its reciprocal? ________________________

52

I THOUGHT THOSE WINGS LOOKED TOO SHORT--- I MUST HAVE MISPLACED A DECIMAL!
DESIGN SECT.

Decimals

The whole system of numbering is called the decimal system because the number ten (Latin decem) is the basis; the positions of the digits correspond to various powers of ten. However, as the word is commonly used, a decimal number is merely a number written with a decimal point located somewhere in it. Fractions and decimals are equivalent ways of writing the same numbers. The means of converting one into the other will be illustrated.

LABELING OF DECIMALS

Millions	Hundred-thousands	Ten-thousands	Thousands	Hundreds	Tens	Units	AND	Tenths	Hundredths	Thousandths	Ten-thousandths	Hundred-thousandths	Millionths
9	3	6	5	2	8	1		0	1	2	9	7	4

(Whole part) (Fractional part)

I. Definition - Decimal fraction

Example

The representation of the fraction whose denominator is some power of ten.

.7, .241, 3.14

II. Working with Decimals

A. Converting decimals to fractions
  1. Numerator - Count the number of digits to the right of the decimal point, then insert the number less the decimal point as numerator.
  2. Denominator - Put number one plus a zero for each digit to the right of decimal.

$$.7 = \frac{7}{10}$$

$$.241 = \frac{241}{1000}$$

B. To convert fractions to decimals, proceed as follows:
Divide the denominator into the numerator.

$$1/4 = \begin{array}{r} .25 \\ 4\,\overline{)1.00} \\ \underline{8} \\ 20 \\ \underline{20} \end{array}$$

C. The steps in the addition of decimals are as fo lows:
  1. Line up decimal points.
  2. Add
  3 Place decimal point directly below in the answer.

$$\begin{array}{r} .7 \\ 7.7 \\ \underline{.77} \\ 9.17 \end{array}$$

Examples

D. To subtract decimals:
  1. Line up decimal points.
  2. Subtract
  3. Line up decimal points in the answer.

From 5.76 subtract 3.94

$$\begin{array}{r} 5.76 \\ \underline{3.94} \\ 1.82 \end{array}$$

E. To multiply decimals:
  1. Multiply numbers
  2. Count number of digits to right of decimal points in multiplicand and multiplier.
  3. Count off from right to left the same number of digits in the product and insert decimal point.

7.06 x .004

$$\begin{array}{r} 7.06 \\ \underline{.004} \\ .02824 \end{array}$$

F. The division of decimals involves the following steps:
  1. Shift decimal in divisor. Divisor must be a whole number.
  2. Shift decimal an equal number of digits in the dividend.
  3. Place decimal in quotient directly above decimal in dividend.
  4. Divide

Divide .72 by .009

$$\begin{array}{r} 80. \\ .009.\overline{).720.} \end{array}$$

III. Changing decimals to fractions of desired denominators is performed as follows:

  A. Multiply by desired denominator.
  B. Round off the answer.
  C. Place over the desired denominator.
  D. DO NOT REDUCE.

.424 to 8ths

$$\frac{.424}{1} \times \frac{8}{8} = \frac{3.392}{8} = \frac{3}{8}$$

Rounding off

3.5 = 4

4.421 = 4

4.521 = 5

Information Sheet DECIMALS

Reference Material

A. In performing the fundamental operations on decimals, remember to:

1. Keep the decimal points lined up when adding or subtracting;
2. Have as many decimal places in the product as you have in both the factors (multiplicand and multiplier);
3. Make the divisor a whole number in a division problem by multiplying the numerator and the denominator by the proper power of ten.

B. To change a decimal into a fraction with any desired denominator, think of the decimal as written with the denominator 1, and then multiply the numerator and the denominator by the required number.

To change .21 into 32nds, write $\frac{.21}{1} \times \frac{32}{32} = \frac{6.72}{32} = \frac{7}{32}$ (approximately)

To change any fraction into one having the desired denominator, it is usually best to first express it as a decimal; and then proceed as above.

C. When reading a decimal number, read the numbers as usual, placing "and" between the whole number and the fraction.

Example: 125.12 is read one hundred twenty-five and twelve hundredths.

D. $\frac{1}{10} = .1$ $\frac{1}{100} = .01$ $\frac{1}{1000} = .001$

Notice that the number of decimal places in the decimal is the same as the number of zeros in the denominator of the fraction.

E. From the meaning of decimal fraction, it is seen that misplacing the decimal point changes the meaning greatly. For each place it is moved to the right, the value of the decimal fraction is multiplied by 10; and for each place it is moved to the left, the value is divided by 10.

1. 33.3 becomes 333.0 when the point is moved one place to the right. This is equivalent to multiplying by 10.
2. 33.3 becomes 3.33 when the point is moved one place to the left. This is equivalent to dividing by 10.

F. Rounding Off Rules: This process is used to reduce the number of figures involved.

1. When figure to be dropped is 5 or more, increase the next figure to the left by one, thus, 251.36 becomes 251.4.
2. When figure to be dropped is less than 5, leave the next figure to the left unchanged, thus 362.34 becomes 362.3.

PROBLEMS

1. Write the decimal form of the following:

   a. One hundred fifty-six thousandths ____________

   b. Nineteen ten-thousandths ____________

   c. Forty-five and sixty-five hundredths ____________

2. Change the following decimals to fractions of lowest terms:

   a. .34 ________ c. .285 ________ e. .3750 ________

   b. .25 ________ d. .013 ________ f. .005 ________

3. Change the following fractions to decimals, carrying each decimal to three places:

   a. 4/9 _____ c. 5/7 _____ e. 7/24 _____ g. 1/3 _____ i. 5/8 _____

   b. 7/12 _____ d. 2/15 _____ f. 3/4 _____ h. 1/6 _____ j. 7/8 _____

4. Match each item in column A with the correct number in column B:

	A	B
________	a. .50	1. .75
________	b. 2/5	2. 1/8
________	c. .16 2/3	3. 1/10
________	d. 5/6	4. 1/2
________	e. .125	5. .833
________	f. .625	6. 1/6
________	g. 7/8	7. .4
________	h. 3/4	8. 5/8
________	i. .1	9. .875

5. Round off the following:

   a. 35.635 to hundredths ________ c. 58.063 to tenths ________

   b. 363.26 to tenths ________ d. .0071 to hundredths ________

Work Sheet **DECIMALS**

6. Solve:

a. 97 + 364.23 + 23.5 + 816.07 ________

b. 8.62 + .223 + 7 58 + '59 ________

c. 96.93 + 7.001 + 5.94 + 24.9 ________

d. .682 + 4.15 + 94.4 + 4.989 ________

7. Solve:

a. From 393.3 take 24.61 ________

b. Subtract .9171 from 1.1646 ________

c. Take 4.758 from 10.39 ________

d. From 457.06 take 362.78 ________

8. Multiply:

a. 454 by 39.06 ________

b. 57.89 by 56 ________

c. .045 by 1238 ________

d 9389 and .87 ________

9. Divide:

a. 22 by 26 ________

b. .8352 by 116 ________

c. 2.913 by .37 ________

d. 9.35 into 50.219 ________

e. 87.5 into 76.82 ________

f. .72 by 9 ________

10. Give the answer to the following in decimal form:
14 1/5 + 12.5 + 28.675 + 15 7/8 + .50 ________

11. From one hundred take seven thousandths. ________

12. Change the following decimals to indicated fractions:

a. .216 to 64ths ____

b. .6437 to 32nds ____

c. .093 to 8ths ____

d. 1.625 to 8ths ____

e. .875 to 8ths ____

f. .925 to 16ths ____

MAN! THIS RATIO VARIES MUCH TOO INVERSELY!!!
THIS PROPORTION IS TOO LUMP SIDED!!
FREIGHT

Ratio and Proportion

Sometimes it is desirable to compare the size of two quantities without paying much or any attention to the actual size of either. In such cases, the idea of ratio is used. For example, the height of two trees may be in the ratio of 2 to 5, meaning that if the first height is considered to be 2 units, the second one will be 5 units, or the first is 2/5 as high as the second. By means of a proportion, we can express the fact that two quantities are changing in the same ratio.

If two quantities are so related that one changes whenever the other one changes, the value of one is dependent upon the value of the other. If these quantities change in the same direction, they are said to vary directly or are directly proportional; if they change in the opposite direction, they are said to vary inversely or are inversely proportional. The ideas of ratio, proportion, direct and inverse variation are discussed in this guide.

Study Guide RATIO AND PROPORTION

I. Ratio

Examples

- A. Definition - A comparison of two quantities expressed in the same units.
- B. Methods of expressing — 5:2, 5/2
  1. Colon (5:2)
  2. Fraction (5/2) — Never 2 1/2
  3. Never expressed as a mixed number
- C. Units of a ratio must be like. - Inches to inches; pounds to pounds; gallons to gallons. — $\frac{5 \text{ inches}}{2 \text{ inches}}$
- D. Reducing - A ratio may be reduced the same as a fraction. — 4/6 = 2/3

II. Proportions

- A. Definition - A statement of equality between two ratios.
- B. Methods of expressing — 5:2 ::10:4 — $\frac{5}{2} = \frac{10}{4}$
  1. Colon (5:2 :: 10:4)
  2. Fraction (5/2 = 10/4)
- C. Nomenclature
  1. "Extremes" are outside terms.
  2. "Means" are inside terms.

$$\overset{\text{Means}}{5:\underbrace{2 :: 10}:4}\quad \text{Extremes: } 5, 4$$

- D. Methods for solving
  1. Written using colons — 5:2 ::10:x
     - a. Multiply extremes — 5x = 20
     - b. Multiply means — x = 4
     - c. Solve resulting equation
  2. Written as a fraction — $\frac{5}{2} = \frac{10}{x}$
     - a. Cross multiply
     - b. Solve for unknown — 5x = 20
     - c. Check answer — x = 4

III. Proportions, direct and inverse

- A. Direct proportion
  1. Definition - Qualities are so related that they vary in the same direction.

2. Solution, steps in

Example

a. Write ratios having the first condition over the second condition $\frac{W_1}{W_2}$ and $\frac{L_1}{L_2}$

b. Reduce $\frac{W_1}{W_2} = \frac{L_1}{L_2}$

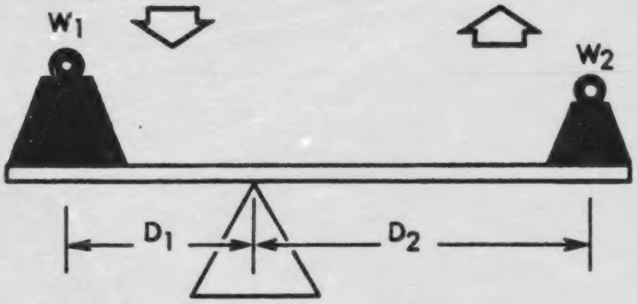
c. Cross multiply $\frac{W_1}{W_2} \times \frac{L_1}{L_2}$

d. Solve for unknown $W_1\ L_2 = W_2\ L_1$

3. Example W = 6, L = 24
W = 8, l = X $\frac{\overset{3}{\cancel{6}}}{\underset{4}{\cancel{8}}}\ \frac{24}{X} = 3X = 96$, X = 32

B. Inverse proportion

1. Definition
Quantities are so related that as one side increases, the other side decreases.



2. Solution, steps in

a. Write the two ratios. Ratios must be expressed in like units. $\frac{W_1}{W_2}$ and $\frac{D_1}{D_2}$

b. Invert either ratio. $\frac{W_1}{W_2}$ and $\frac{D_2}{D_1}$

c. Reduce $\frac{W_1}{W_2} = \frac{D_2}{D_1}$

d. Cross multiply $\frac{W_1}{W_2} = \frac{D_2}{D_1}$

e. Solve for unknown $W_1\ D_1 = W_2\ D_2$

Reference Material

A. Ratio

To find the ratio of two magnitudes, write them in the same units and express the quotient as a reduced fraction, making the numerator the first mentioned magnitude. Example:

The ratio of 4 inches to 2 1/2 feet is 4/30 or 2/15.

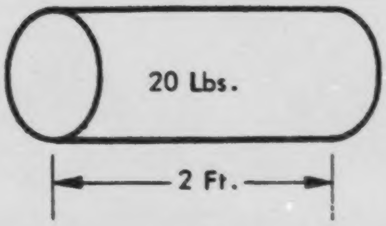
A ratio may be expressed as a fraction a/b or with a colon as (a:b), but never as a mixed number.

B. Proportion

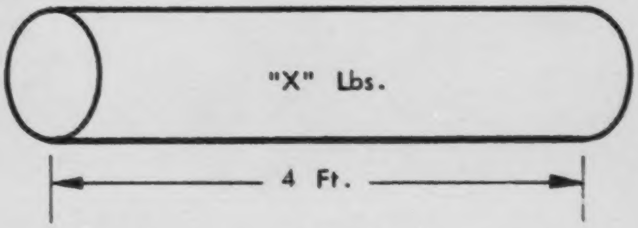
A proportion is a statement that two ratios are equal. If the ratios a/b and c/d are equal, this can be expressed by $a/b = c/d$ or by a:b: :c:d. When the proportion is written in the latter form, the two outside numbers are known as the extremes and the two inside numbers are the means. The rule for cross-multiplication of two fractions becomes, in this case, the product of the means equals the product of the extremes. Thus $ad = bc$.

C. Direct variation

If two quantities are so related that their ratio is constant, they are said to vary directly as each other. To meet this qualification, the value of the quantities changes at the same relative rate and in the same direction. An example of such variation is the relationship between the circumference and the diameter of a circle. Their ratio is equal to the constant pi, for $\pi = c/d$. If "d" decreases, "c" must also decrease. If "c" increases, "d" must also increase. Another example of such variation is the length of a uniform steel rod to the weight. (The greater the length, the greater the weight.)



A



B

In order to find the value of the unknown weight, a proportion must be set up and solved as follows:

$$\frac{W_1}{W_2} = \frac{L_1}{L_2}$$

$$\frac{20}{x} \times \frac{2}{4}$$

$$2x = 80$$

$$x = 40 \text{ lbs.}$$

D. Inverse variation

If two quantities are so related that their product is a constant, they are said to vary inversely as each other. Inverse means "opposite in order, or inverted". This implies that as one quantity increases, the other quantity decreases, or as one decreases, the other increases. For example: If the area of a rectangle is fixed (equal to a constant), then the base varies inversely as the height.

If the area of a rectangle is given as 48 sq. ft., then the relation between the base and height is expressed by the formula 48 = bh. Any increase in the value of "b" must be accompanied by a corresponding decrease in "h" so that their product will remain 48.

PROBLEMS (DIRECT VARIATION)

1. If 6 apples are purchased for $.24, how many apples could be purchased for $.32?
   ____

2. The ratio of a propeller r.p.m. to an engine r.p.m. is 2 to 3. If the propeller is turning at 2400 r.p.m., what is the engine r.p.m.? __________________

3. If 320 bushels of corn are harvested from 4 acres of land, how many bushels will be harvested from a farm of 160 acres when the same amount is harvested per acre? __________________

PROBLEMS (INVERSE VARIATION)

1. If 30 men can eat 270 pounds of food in 6 days, 45 men will eat the same amount in how many days? __________________

2. If it takes 7 hours to drive a certain distance at 40 miles per hour, how fast must a car be driven to travel the same distance in 5 hours? __________________

3. If it takes a plane 4 hours to make a trip at 140 miles per hour, what must be the speed to make the trip in 3 1/2 hours? __________________

PROBLEMS (DIRECT AND INVERSE VARIATION)

1. The time to travel a given distance varies inversely as the speed. If it takes 4 hours to make a trip at 50 miles per hour, how long will be taken to make the trip at 40 miles per hour? __________________

2. The weight of a steel rail 8 feet long is 460 pounds. What will be the weight of a second rail of the same structure which is 14 feet long? __________________

3. Find the ratio of the following:

   a. 3 feet to 12 feet __________________
   b. 12 gallons to 36 gallons __________________
   c. 9 yards to 6 inches __________________
   d. 9 inches to 6 inches __________________
   e. 2 feet to 1 yard __________________
   f. 1 pound to 12 ounces __________________

4. A stake 10 feet high casts a shadow 8 feet long at the same time that a tree casts a shadow 60 feet long. What is the height of the tree? __________________

64

5. The rate of rotation of gears meshed together is inversely proportional to the number of teeth. If a gear with 24 teeth makes 1200 revolutions a minute, what is the rate of rotation of an 18-tooth gear meshed with it? ________

6. If it takes 25 men 37 days to complete a given job, how long would it take 34 men to do the same job? ________

7. If 24 lbs. of maple sugar cost $36, how much must be paid for 5 lbs.? ________

8. A manufacturing plant turns out 7500 concrete blocks in 6 days. How large an order for concrete blocks can be filled in 20 days? ________

9. If 10 men can dig a ditch in 12 days, how many days will it take 15 men to dig it? ________

10. An airplane flying 120 miles per hour covers a distance in 3 hrs. and 15 min. At what rate would it have to fly to cover the same distance in 2 hrs. and 30 min.? ________

11. If a boat drifts downstream 40 miles in 12 hrs., how far will it drift in 15 hrs.? ________

12. The upkeep on 62 trucks for a year is $3100. What would be the upkeep of 48 such trucks for 1 year at the same rate per truck? ________

13. If a 60 lb. weight applied 4.5 ft. from the fulcrum balances a second weight located 5 ft. from the fulcrum, what is the second weight? ________

14. If it takes a car 3 hrs. to travel a given distance at 40 miles per hour, how long will it take a car to travel the same distance at 45 miles per hour? ________

15. If 4 tons of coal cost $75, how much will 14 tons cost at the same price per ton? ________

16. A garrison of 140 soldiers consumed 26 barrels of flour in 9 weeks. How many days would the same amount of flour last a garrison of 210 soldiers? ________

17. A grocer's sales for 6 days amounted to $720. At that rate, find out what his sales would be for 26 days? ________

18. Find the tax on property assessed at $12,000, if the tax on property assessed at $3500 is $42. ________

19. A snapshot is 2 1/2 in. long and 1 1/4 in. wide. An enlargement of it is 3 3/4 in. wide. How long is the enlargement? ________

20. If the current in an electrical circuit is 24 amp. when the resistance is 19 ohms, what is the current when the resistance is increased to 21 ohms? ________ (Amp. and ohms are inversely related.)

AND I THOUGHT I HAD FIGURED ALL THE ANGLES!

Angles

An angle is usually thought of as an "opening" between two intersecting straight lines. However, for some purposes this concept is not satisfactory. For example, a propeller blade may make a complete rotation, so that the two positions of the blade coincide and there is no "opening" in evidence. However, there is a feeling that an angle has been swept out by the blade. If it makes two rotations, there is a feeling that a different angle has been swept out than when it made one rotation, but in both cases there is no visible opening between the positions of the blade. Thus, to take care of these situations — as well as the usual one — an angle is defined in general terms and measured in appropriate units. The method of adding and subtracting angles is illustrated, and a general classification of angles according to size is given.

THE VOLUME OF A GIVEN MASS OF GAS VARIES INVERSELY WITH PRESSURE WHEN THE TEMPERATURE REMAINS CONSTANT.

Robert Boyle
1627 - 1691
Britist scientist

BOYLE'S LAW

If a pint of liquid is poured into a larger container, it will occupy only a pint of the volume. However, if a pint of gas were transferred to a larger container, it would occupy all of the new volume. The reason for this action is the property of a gas to expand unless it is held under the same pressure.

Robert Boyle investigated this relationship between the volume and the pressure of a given weight of dry gas and found that if he held the temperature constant, the pressure and the volume varied inversely to each other. From his experiments, mathematical formulas have been developed which enable us to predict what will happen to a gas with respect to its volume and to its pressure.

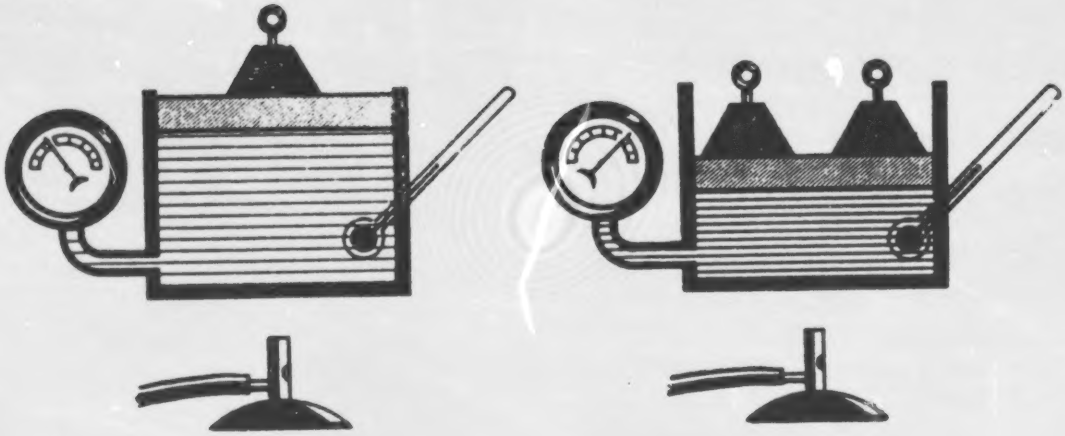
The useful applications of Boyle's Law are many and varied. Some of these applications which are more common to aviation are: the carbon dioxide (CO_2) bottle that is used to inflate life rafts and life vests; the compressed oxygen and the acetylene tanks used in welding; the compressed air brakes and shock absorbers; and the use of oxygen tanks for high-altitude flying and emergency use.

Mathematically, the relationship is used to find an unknown volume or pressure of a dry gas when a given set of conditions is used for comparison. Another lesson will be devoted to the relationship between temperature and volume.

1. STATEMENT OF BOYLE'S LAW

2. EXPLANATION OF BOYLE'S LAW

Using a given pressure and volume as the standard set of conditions while holding the temperature constant, any change in pressure or volume will cause an inverse change in the other.



3. FORMULA $V_1 P_1 = V_2 P_2$

   a. Meaning of parts

      V_1 =

      P_1 =

      V_2 =

      P_2 =

   b. Problem

4. APPLICATION TO AVIATION

   a. Mathematical

   b. Practical

Work Sheet **BOYLE'S LAW**

1. Boyle's Law states that the__________________varies______________________ as the____________________ if the _________________ is__________________.

2. The effect on a dry gas caused by an increase in pressure (holding the temperature constant) would be ____.

3. If the volume of a dry gas is increased from 500 cubic inches to 1000 cubic inches, the pressure will ____.

4. A cylinder contains 200 cubic feet of dry gas under a pressure of 20 pounds per square inch. Keeping the temperature constant while adding 5 pounds per square inch more pressure, find the new volume.

5. An engine cylinder contains 100 cubic inches of dry gas at a pressure of 25 pounds per square inch. Find the amount of pressure needed to make the volume 250 cubic inches (holding temperature constant).

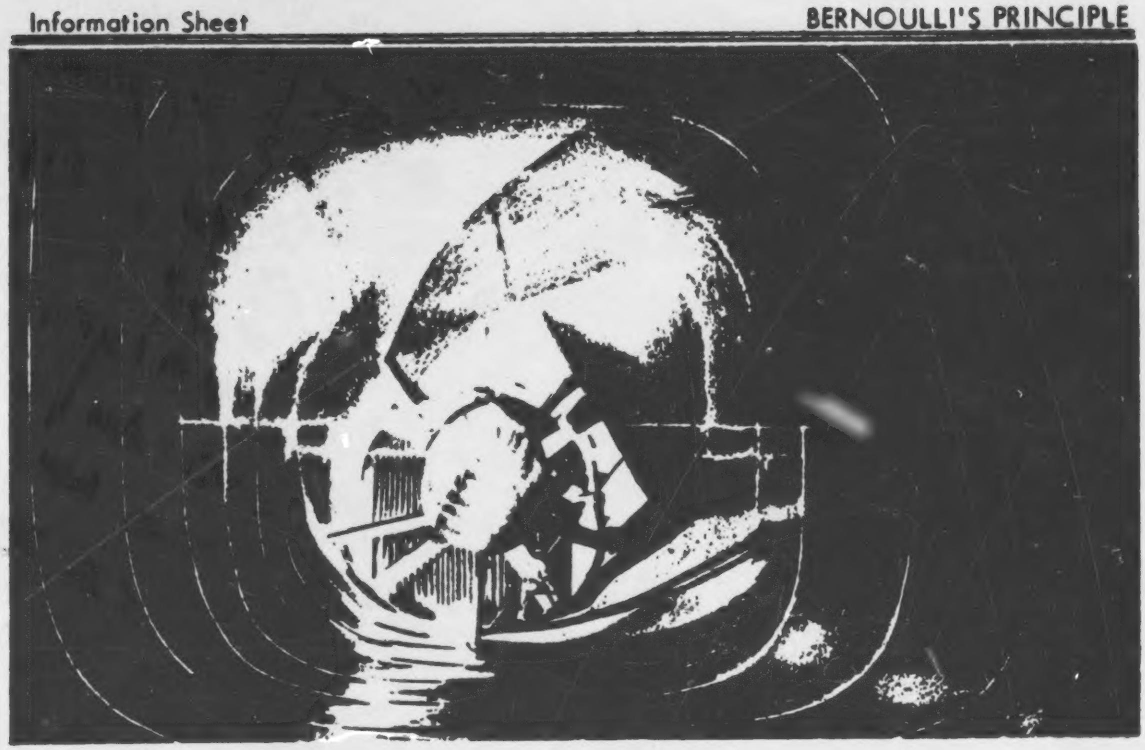
6. The amount of pressure necessary to change a volume of gas, now at 15 pounds per square inch, from 1200 cubic inches to 600 cubic inches is:

7. The reason behind the use of a carbon dioxide (CO_2) bottle for filling the life raft, according to Boyle's Law, is ____
____.

8. Which weighs more, a full or an empty oxygen tank? _______________________.

9. When dealing with atmospheric pressure, normal atmospheric pressure of 15 pounds per square inch must be considered. An aircraft tire has a volume of 500 cubic inches of air under a tire pressure gage reading of 40 pounds per square inch. Find the volume this gas would occupy if it were released to atmospheric pressure.

10. A decrease in volume of 25% would cause________________________in pressure of____________________% providing ___________________________________.



BERNOULLI'S PRINCIPLE

Previous lessons have dealt with problems involving pressures that have been transmitted by enclosed fluids. Science often wondered what might happen if pressure was considered from the standpoint of acting on a fluid that was free to flow. Bernoulli, a Swiss scientist and mathematician, is credited with the principle that bears his name, and upon which aviation depends for flight of its aircraft.

The principle was first applied to liquids moving freely through tubes that had a constricted portion, to determine the relationship that exists between pressure and velocity. It was found that when the velocity shows the greatest, the pressure shows the least. The experiments were then performed with gases and from these latter experiments came the airfoil and venturi which are so vital to the theory of flight.

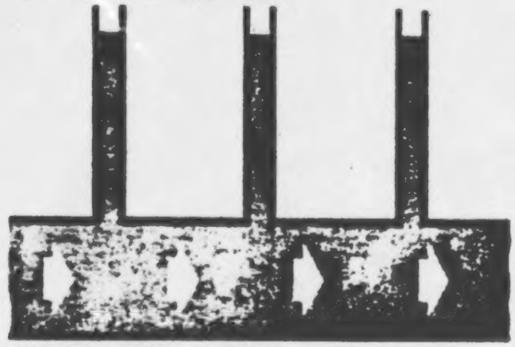
The air above the earth is a fluid (gas) which is not enclosed and thus is the media which supports our aircraft. Sustained flight of an airplane depends upon the density of the atmosphere through which it is traveling and the speed (velocity) which it must provide with its power plant. The design and development of the airfoils of the fuselage, wings,and controlling surfaces must be determined by experiments in wind tunnels with scale models before the full-scale plane is built.

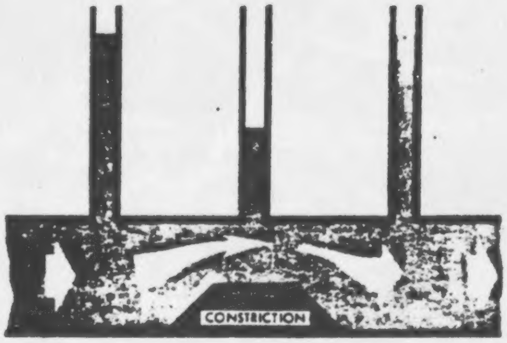
1. STATEMENT OF PRINCIPLE

2. DEVELOPMENT OF PRINCIPLE

   a. Straight tube

   b. Constricted tube

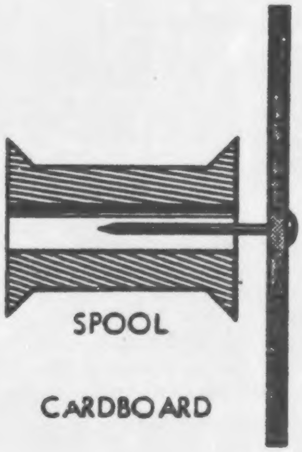


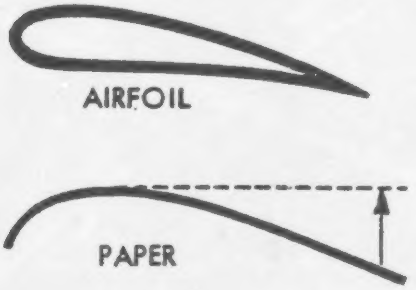


3. DEMONSTRATIONS

   a. Venturi effect — The increased velocity of the air passing the constricted opening reduces the pressure at that point; atmospheric pressure, being greater, acts to force the cardboard against the spool.

   b. Airfoil effect — The increased velocity of the air across the upper surface reduces the pressure upon that surface; atmospheric pressure, being greater, acts to force the foil upward.





4. APPLICATION TO AVIATION

a. Venturi tube

(1) Description

(2) Operation

(3) Use in aviation

b. Carburetor venturi

(1) Description

(2) Operation

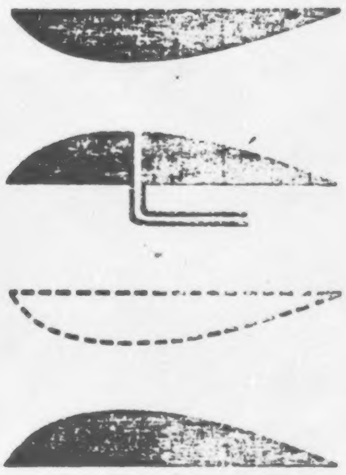
(3) Use in aviation

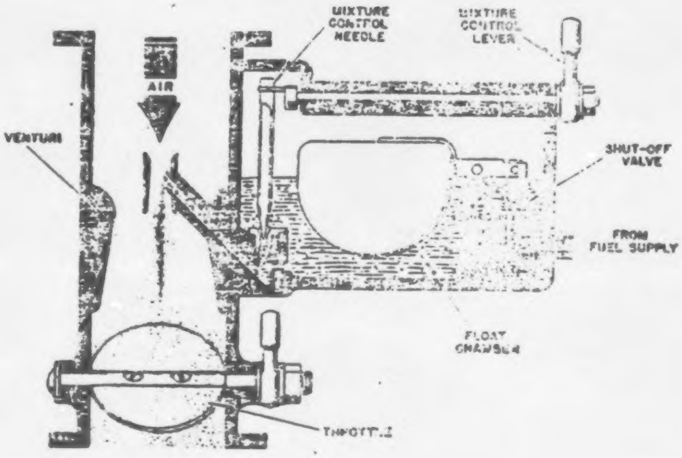
c. Airplane airfoil (half venturi)

(1) Description

(2) Operation

(3) Use in aviation




MIXTURE CONTROL NEEDLE
MIXTURE CONTROL LEVER
AIR
VENTURI
SHUT-OFF VALVE
FROM FUEL SUPPLY
FLOAT CHAMBER
THROTTLE

Work Sheet BERNOULLI'S PRINCIPLE

1. Bernoulli's Principle states that the ______________ within a ____________________ fluid varies ______________________ as the _______________ of the moving fluid.

2. When the velocity of the fluid is great, the pressure is ______________________.

3. When the ____________________ is small, the _________________________ is great.

4. The ______________________ of fluid passing any given point in a venturi tube will be ____.

5. The velocity of air passing across the upper surface of an airfoil is ______________ than the velocity across the lower surface.

6. An airfoil gets its lift from ____.

7. The venturi tube on an aircraft is used to ____________________________________.

8. Will the venturi tube principle hold true for liquids? __________________________.

9. In the experiment with a paper airfoil, the paper had a tendency to ______________ ______________ due to ____.

10. In the experiment with a spool venturi, the cardboard had a tendency to __________ ________________ due to ____.

11. The tear drop shape of airplane airfoils eliminates a condition known as ___ ______ ____.

12. In the diagram of the venturi tube, the velocity of the air entering and leaving will be ____ than at the constricted portion.

13. In the drawing of the airfoil, the velocity across the upper surface will be __________ ______________ than across the lower surface, while the pressure will be __________.

14. In the drawing of the carburetor venturi, the pressure at the jet will be __________ ________________ than atmospheric pressure at the vent opening.

HEAT

The subject of heat (or kinetic energy) is one of the more important topics in the average physics course; however, time allows for only a brief description of heat and how it is transferred.

Quite in contrast to temperature, which has relative coldness and hotness, heat can be measured in actual units of energy. Many mechanical devices as well as electrical devices operate on energy and produce heat in some form or other. In some instances, heat energy may prove beneficial. In other situations, it can be dangerous. In our study of physics and its relation to aviation, we note that heat energy furnishes the power for flight in reciprocating and jet-propelled engines. Protective insulation must be provided in some instances to contain heat, to direct it to where it can prove useful, or to carry it off. It may also be noted that heated air currents provide the Aerographer with data for use in weather forecasting.

Heat energy is the result of the motion of molecules within a body of matter. The faster the motion, the more heat there is generated. The transfer of this heat energy by means of conduction, convection, and radiation must be thoroughly understood in order to utilize the best possible means of transfer and also to avoid any of the dangers of improper transfer. What might prove highly beneficial in one situation might prove damaging in another. In learning to "handle" heat transfer, you will also learn the safety precautions.

The two most common measures of heat are associated with the English and Metric systems of measurement. The British Thermal Unit (BTU) and the calorie have widespread usage in a variety of things from home heating to dieting and of course -- aviation.

1. DEFINITION OF HEAT

2. MEASUREMENT OF HEAT

    a. Units of Measurement

        (1) Calorie ____________ System

        (2) British Thermal Unit ____________ System

    b. Use of Heat Units

        (1) Calorie

        (2) British Thermal Unit

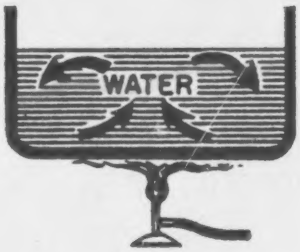
3. METHODS OF HEAT TRANSFER

    a. Conduction

        (1) Definition

        (2) Explanation

        (3) Use in aviation



    b. Convection

        (1) Definition

        (2) Explanation

        (3) Use in aviation

    c. Radiation

        (1) Definition

        (2) Explanation

        (3) Use in aviation

Work Sheet — HEAT

1. The Metric System of heat measurement uses the ________________________.

2. The ________________________ is the English system's heat unit.

3. A ________________ of heat is needed to raise the temperature of ____________ gram of water ________________ on the ________________________ scale.

4. The number of British Thermal Units (BTU'S) needed to raise the temperature of 15 pounds of water 10 degrees on the Fahrenheit scale will be ________________.

5. The number of calories needed to raise the temperature of one gram of water from 10 degrees Centigrade to 25 degrees Centigrade will be ____________________.

6. Heat energy is transferred through a solid object, such as a piece of wood, by the method called ____.

7. The method for transferring heat energy through matter, such as gases or liquids, is known as ____.

8. The method of heat transfer which will operate through a vacuum is called ________ ____.

9. Air conditioning units depend on the ________________ method of heat transfer in their operation.

10. That color which will produce the best absorption of heat energy will be ________ ____.

11. The color ________, which produces the greatest amount of heat reflection, is used on aircraft which fly at high altitudes.

TEMPERATURE

Quite frequently we hear people discussing the temperature in relation to the weather and then rarely doing anything about raising or lowering the temperature around them. About all they do is "read" a thermometer and discuss how hot or how cold it was at some other time. We all "feel" the temperature but it is really difficult to measure.

If you put one hand in a bucket of hot water and hold the other hand in a bucket of cold water for a few minutes and then place both hands in a bucket of warm water, both hands will "feel" the difference. This is a "sensation" caused by the change of temperature and may be taken as a simple explanation of temperature.

Several early scientists from time to time conducted experiments with the expansion of liquids in an attempt to develop temperature scales. Various limits were set as starting points for "measuring" temperature. Some of these limits included the coldest winter day on record; the body temperature of cows, deer, and humans; ice-salt solutions; melting ice, and boiling water. The latter two were finally adopted and establish the limits now used on most thermometers.

Mercury and alcohol are the two liquids used in ordinary thermometers today. Regardless of the scale used, the liquid expansion determines the change in temperature reading. The scales have divisions called degrees and two limiting values called the boiling point and the freezing point.

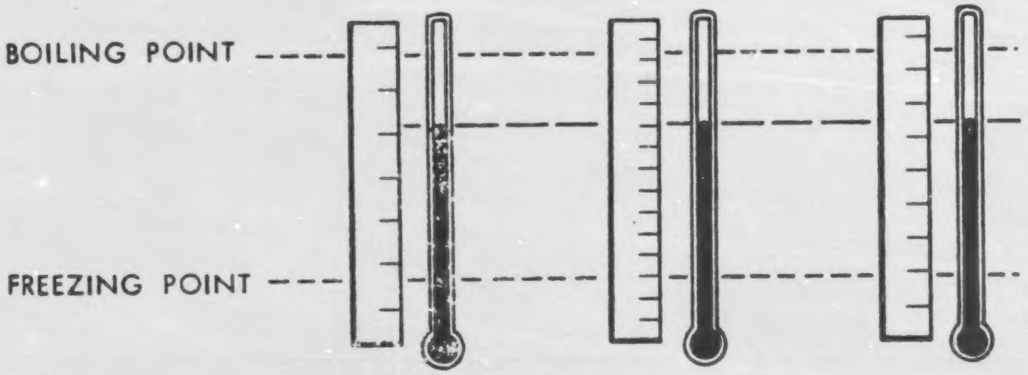
1. DEFINITION OF TEMPERATURE

2. MEASUREMENT OF TEMPERATURE

   a. Unit of measure

   b. Development of scales

      (1) Select three glass tubes with uniform inside diameters.
      (2) Fill each with the same amount of mercury.
      (3) Close both ends of each tube.
      (4) Place all three tubes on a block of melting ice.
      (5) Mark the lowest level of the mercury as FREEZING point.
      (6) Place all three tubes into boiling water.
      (7) Mark the highest level of mercury as BOILING point.
      (8) NOTE THAT ALL THREE TUBES OF MERCURY HAVE THE SAME LIMITS.
      (9) Fix three scales, each with independently marked divisions.
      (10) NOTE THAT EACH SCALE READS DIFFERENTLY.



   c Scales used

      (1) Fahrenheit: ____________________ System

      Reference Points: Freezing ________________ Boiling ________________

      Number of divisions between reference points ________________________

      Readings are made __________________________ from ________________

(2) Centigrade: ________________________System

Reference points: Freezing __________Boiling________________

Nu Numbers of divisions between reference points ________________

Readings are made____________________from____________________

(3) Absolute: ________________________System

Reference points: Freezing __________Boiling________________

Number of divisions between reference points__________________

Readings are made____________________from____________________

d. Conversion of Scale Readings

(1) Centigrade to Fahrenheit

Formula:

Problem:

(2) Fahrenheit to Centigrade

Formula:

Problem:

(3) Centigrade to absolute

Formula:

Problem:

3. APPLICATION TO AVIATION

Work Sheet TEMPERATURE

1. The boiling point of water is ____________________ degrees Centigrade, while for Fahrenheit, it will be ____________________ degrees.

2. The freezing point of water is ______________ degrees Fahrenheit, while for Absolute, it will be ______________ degrees.

3. A reading of 113 degrees Fahrenheit will be equal to how many degrees Centigrade?

4. A reading of minus 40 degrees Centigrade will be equal to how many degrees Fahrenheit?

5. A reading of 40 degrees Fahrenheit will be equal to how many degrees Centigrade?

6. A reading of minus 4 degrees Fahrenheit will be equal to how many degrees Centigrade?

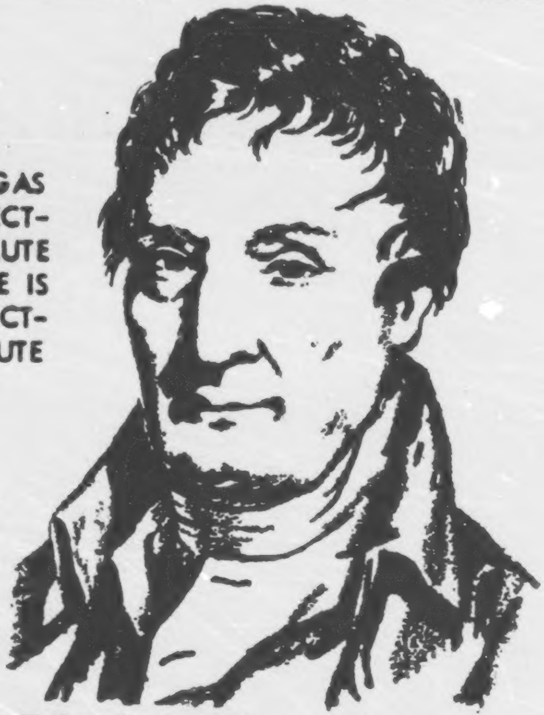
7. A reading of minus 76 degrees Centigrade will be equal to how many degrees Absolute?

8. The cylinder-head temperature gauge in the cockpit of an aircraft reads 147 degrees Centigrade. When converted to Fahrenheit, this temperature will read how many degrees Fahrenheit?

9. A blast furnace has a temperature reading of 975 degrees Fahrenheit. If this is converted to Centigrade, it will read how many degrees Centigrade?

10. A cold storage locker has a temperature reading of minus 58 degrees Fahrenheit. Converted to Centigrade, this will read how many degrees Centigrade? Converted to Absolute, this will read how many degrees Absolute?

IF THE VOLUME OF A CONFINED GAS IS CONSTANT, THE PRESSURE IS DIRECTLY PROPORTIONAL TO THE ABSOLUTE TEMPERATURE, OR IF THE PRESSURE IS UNCHANGED, THE VOLUME IS DIRECTLY PROPORTIONAL TO THE ABSOLUTE TEMPERATURE.



Jacques Charles
1746 - 1823
French scientist

CHARLES' LAW

The lesson on Boyle's Law brought out the relationship that existed between the volume and the pressure of a dry gas if the temperature was held constant. This lesson will deal with the relationship that exists between the volume and the temperature, if the pressure is held constant. There is one condition which must be taken into consideration to avoid mathematical errors in figuring this relationship -- all temperature readings must be expressed in absolute temperature.

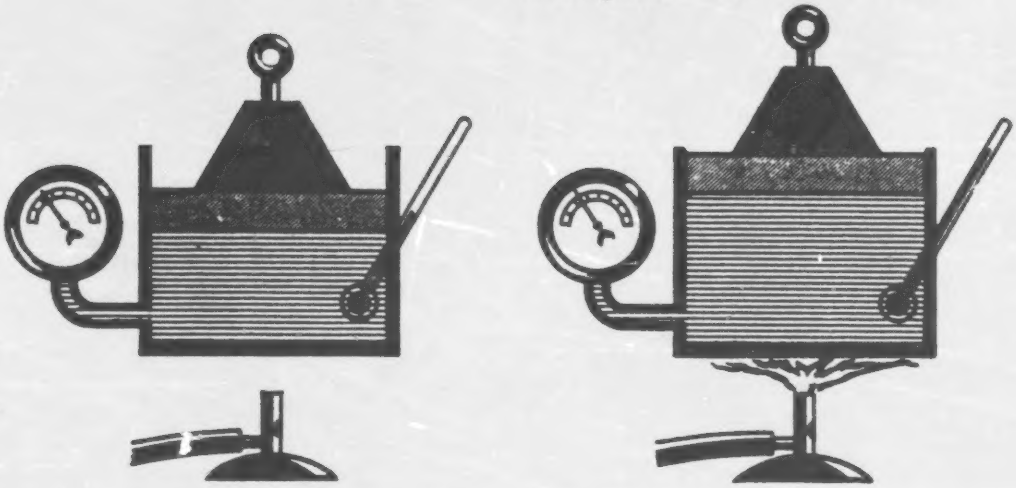
The French physicist, Jacques Charles, performed experiments which proved that gases expand when they are heated, and that if the pressure is held constant, the expansion is in direct proportion to the temperature rise. This may be illustrated by reference to early steam engines which had huge pistons and yet produced a small amount of power compared to the well developed gasoline and diesel engines with much smaller pistons capable of producing enormous power.

Flights into the stratosphere of free balloons, the expanding gases of jet-propelled aircraft, the recordings of instruments depending upon the actions of clouds or other weather data, may be explained by the use of Charles's Law. Here are practical applications of a law of physics that aid the pilot, air controlman, and aerographer in their work. Flying is made safer when humans are able to apply this law in handling weather data so vital to aviation.

CHARLES' LAW

1. STATEMENT OF CHARLES' LAW

2. EXPLANATION OF CHARLES' LAW Using a given temperature and volume as a set of standard conditions, any change in temperature or volume will cause a direct change in the other, providing the pressure is held constant and absolute temperature readings are used.



3. FORMULA $V_1 T_2 = V_2 T_1$ and $P_1 T_2 = P_2 T_1$

   a. Meaning of parts

      $V_1 =$
      $T_2 =$
      $V_2 =$
      $T_1 =$
      $P_1 =$
      $P_2 =$

   b. Problem

4. APPLICATION TO AVIATION

   a. Mathematical

   b. Practical

Work Sheet

CHARLES' LAW

1. Charles' Law is true for ______________________ only.

2. Charles' Law states that a ____________ and a ____________________ vary ________________ if the __________________ is held constant, and the _______________ is measured on ________________ scale.

3. Heating a gas ______________________ change its weight.

4. Absolute temperature scale readings are used in mathematical problems for Charles' Law because ______________________________________.

5. Heating a gas changes its ______________________________.

6. The volume of a dry gas is 400 cubic inches at 20 degrees Centigrade. Holding the pressure constant, find the volume of this same gas when the temperature is a minus 10 degrees Centigrade.

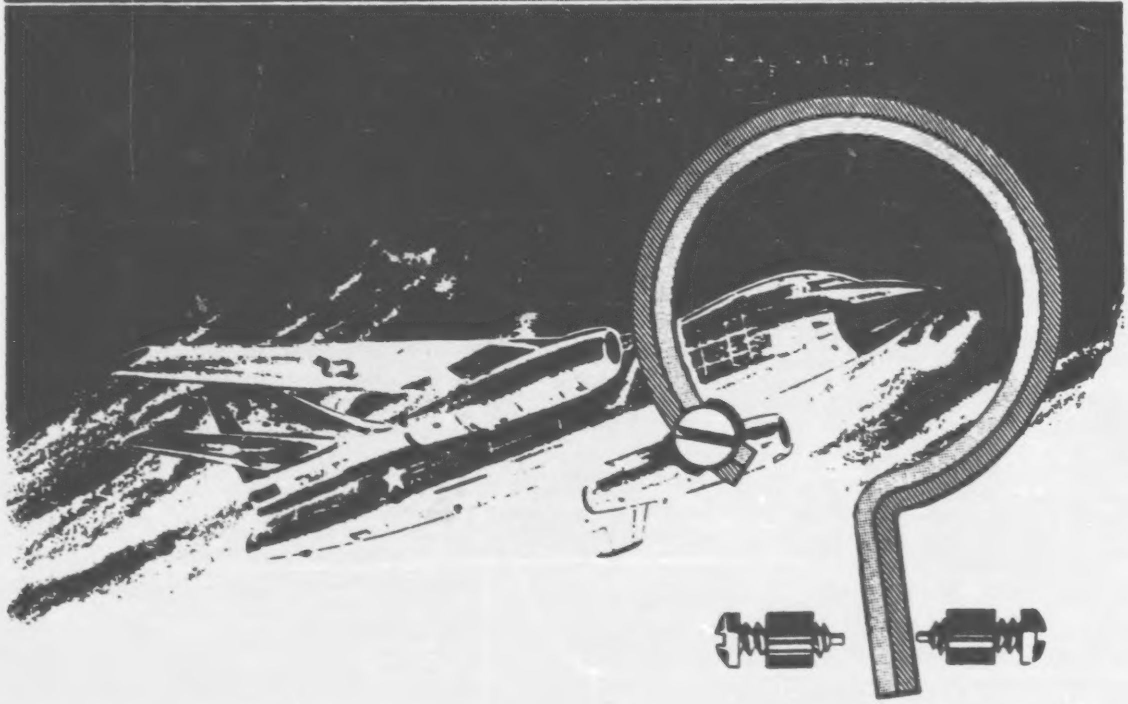
7. The volume of a dry gas is 2 cubic feet. Find the new volume if the temperature has changed from 100 degrees Absolute to 200 degrees Absolute while holding the pressure constant.

8. Find the Absolute temperature required to change 5 cubic feet of dry gas to 4 cubic feet, if the original temperature was 100 degrees on the Absolute scale.

9. The temperature of a dry gas is 27 degrees Centigrade and its volume is 450 cubic inches. If the temperature is raised to 100 degrees Centigrade, while holding the pressure constant, the new volume will be:

10. The volume of a dry gas at 173 degrees Absolute is 40 cubic feet. The volume is increased by 30 cubic feet while holding the pressure constant. The new temperature will be :

11. Absolute Zero equals ____________ degrees Centigrade.



THE COMPOUND BAR

In earlier lessons, we have learned that heat energy and its effect on matter may be beneficial or extremely dangerous. It was also noted that heat may affect different materials in a variety of ways. Some materials expand faster than others. Some change from one state to another under varying conditions. Terrific heat causes the formation of alloys in metals in certain situations and that same amount of heat will cause some other substance to fall apart.

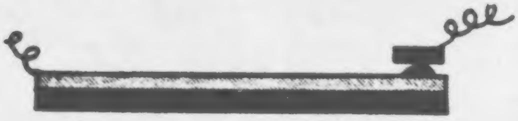
By practically applying the information he has on heat, man has avoided disaster and utilized this knowledge to a great advantage. One of the most useful devices which uses the relativity of coefficients of expansion of two different materials is called the compound bar. This device is used in electrical circuits to control current flow in the circuit. It acts either as a safety device or as an automatic switch. Air conditioning units, refrigerators, flashing light systems, and circuit breakers are among the common things that utilize the compound bar.

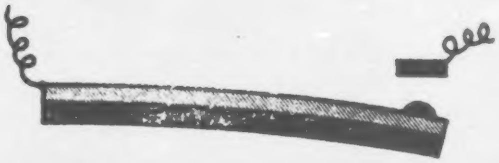
When the two different materials are firmly fastened together, they operate as a single unit with the application of heat. The compound bar when heated bends toward the side which has the lowest expanding ratio and bends in the opposite direction when it is cooled. This action operates a contact point to make or break electrical circuits, open or close automatic fire sprinkler systems, or flash on and off running lights and such other devices where heating and cooling action is present within the system.

1. DESCRIPTION

2. PRINCIPLE OF OPERATION

3. EXPLANATION





4. APPLICATION TO AVIATION

a. Thermometer (metallic)

(1) Operation

(2) Use in aviation

b. Thermostat

(1) Operation

(2) Use in aviation

c. Circuit Breaker

(1) Operation

(2) Use in aviation

1. The principle of the compound bar is dependent upon ______________________

rates of ____________________ of ______________________________.

2. The two most common materials used are ______________ and ______________.

3. Should the compound bar be made up of materials other than metal, will it still operate?

4. A certain compound bar is heated; the unit will tend to bend towards that

______________________ having the __________ rate of ____________.

5. A certain compound bar is made up of brass and iron. When the heat is withdrawn,

the bar will tend to bend towards ______________________________.

6. A platinum wire can be imbedded into a glass without damage to the glass due to temperature changes. Copper wire cannot be used in such a case because:

7. Are all thermostats operated by means of a compound bar? __________________.

If not, what other means may be used? ______________________________.

8. Thermostats are used in aircraft for ______________________________,

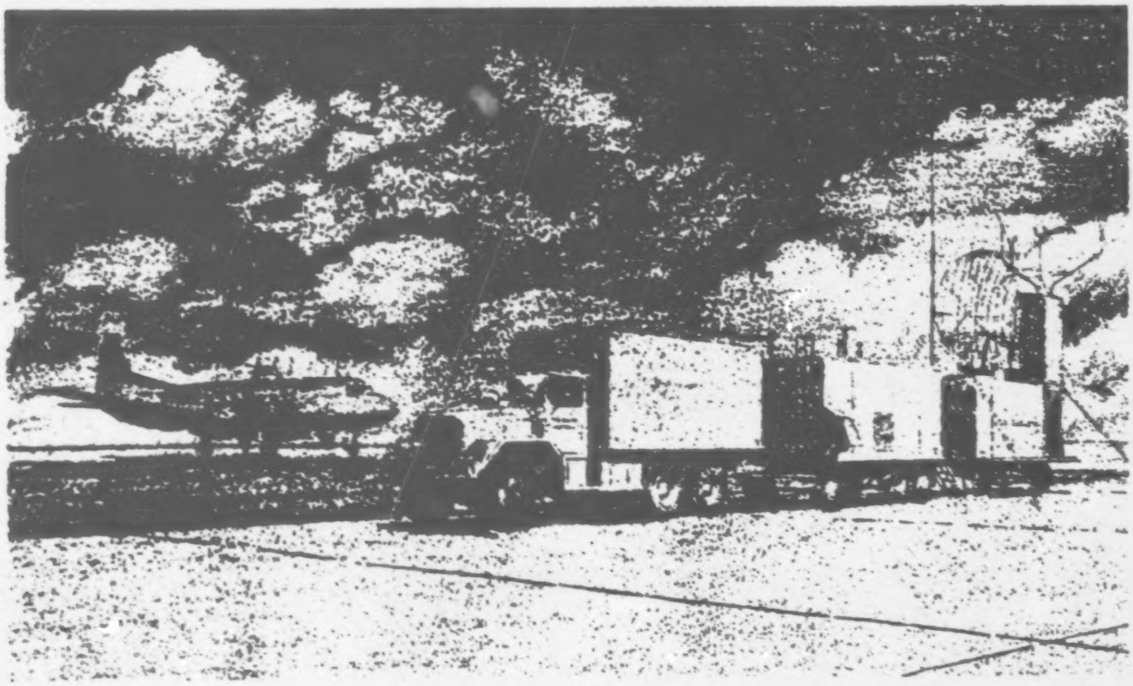
________________________ and ______________________________.

9. ______________________ must be reset manually, while ______________

reset themselves automatically. Thus __________________ are safety devices.

10. The compound bar principle serves aviation principally as __________________

____.



HUMIDITY

So far in this text we have used the word "fluid" to represent both liquids and gases. It now becomes necessary to study them separately -- that is, in their relationship, or ratio, to each other. This ratio is known as relative humidity and plays an important role in everyday applications of industry and in particular aviation.

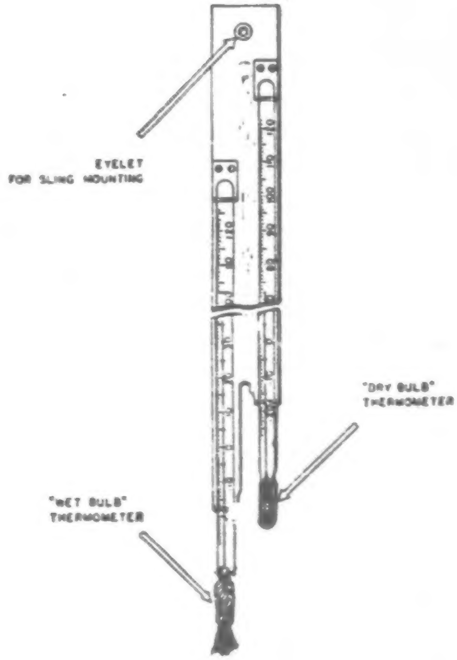
Humidity is the amount of water vapor present in the air at any given time. Humidity depends upon temperature conditions, pressure conditions, and dew point. Dew point is that point at which saturation takes place and when rainfall occurs.

Relative humidity is the ratio of the amount of moisture a given block of air actually does hold to what it could hold under certain conditions. This fact is important to Aerographers in making weather forecasts. It is also important to personnel concerned with the proper stowage of certain materials; for the development of equipments to be used in connection with aviation activities in various places in the world, and for mechanical devices to assist in flying aircraft, especially at high altitudes.

The "wet-dry" bulb thermometer is used to compute relative humidity simply and quickly. The de-icer equipment on airfoils and in carburetor venturi are two applications of devices to combat critical stages of relative humidity.

1. HUMIDITY
   - a. Definition
   - b. Dependent upon conditions:
     - (1) Temperature
     - (2) Pressure
     - (3) Precipitation (dew point)
   - c. Application to aviation

2. RELATIVE HUMIDITY
   - a. Definition
   - b. Formula $\text{R.H.} = \frac{\text{DOES}}{\text{COULD}}$
   - c. Problem
   - d. Application to aviation
     - (1) Aerographer
     - (2) Wet-dry thermometer
     - (3) De-icer gear


EYELET
FOR SLING MOUNTING
"DRY BULB"
THERMOMETER
"WET BULB"
THERMOMETER

Work Sheet HUMIDITY

1. Humidity is the ______________ of moisture ______________ in the air.

2. Relative humidity is the ______________ of ______________ to ______________.

3. Relative humidity is always measured in ______________________________.

4. Relative humidity ______________ when temperature ______________.

5. Relative humidity ______________ when pressure ______________.

6. Dew point is ______________________________.

7. Air cooled below ______________ causes precipitation.

8. If the air in this room should actually contain 2 grains of water vapor per cubic foot, but could hold 2.113 grains per cubic foot if saturated, find the relative humidity if the temperature is at 32 degrees Fahrenheit.

9. If the air in this room actually contains 2 grains of water vapor per cubic foot, but actually could hold 7.48 grains per cubic foot at 68 degrees Fahrenheit, find the relative humidity.

10. In comparing the two previous problems, as the temperature increased, the relative humidity ______________________________.

11. One use of the wet-dry thermometer is to measure ______________.

12. That rating which uses data on humidity and relative humidity most often is the ______________________________.

13. ______________ gear is used to prevent ice formation on ______________ ______________ and in ______________.

14. The air in a particular storage magazine (ammunition) must be held to certain temperature limitations. This may be accomplished partly by regulating the ______________________________.

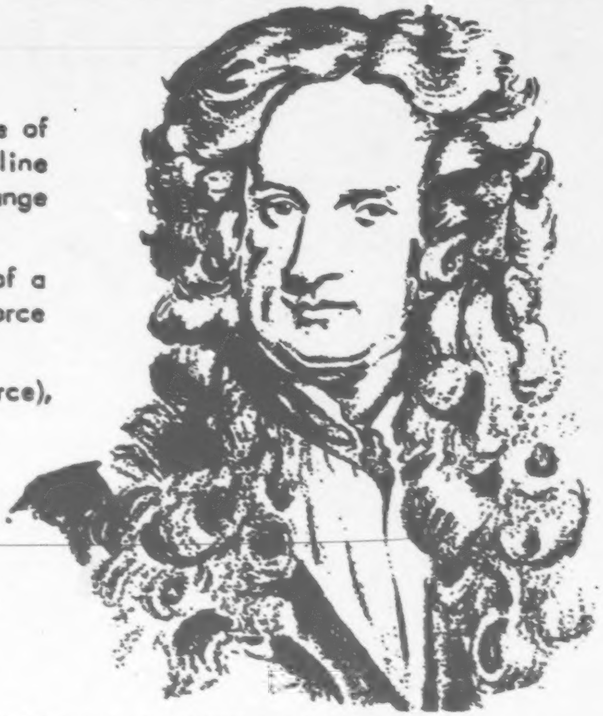
15. Naval ships are preserved in the "Moth Ball Fleet" by use of special ______________ ______________ which maintains ______________ requirements.

NEWTON'S LAWS

INERTIA: Every body persists in a state of rest or of uniform motion in a straight line unless compelled by external force to change that state.

ACCELERATION: The acceleration of a given body is proportional to the force causing it.

INTERACTION: For every action (or force), there is an equal and opposite reaction.



Sir Isaac Newton
1642 - 1727
English mathematician and physicist

FORCE AND MOTION

Force has been discussed previously and the results were usually expressed in terms of pressure. Now we find that there is another result of force acting upon matter and this force is expressed in terms of motion. Again we must refer to the value of Newton's Laws of Motion involving "inertia," and "action and reaction." They play important roles in the constant development of aviation.

The resultant force of several forces acting in combination can be found by a simple method called "composition of forces" or the "parallelogram method." This is performed by the two forces acting at a given angle to each other. This method is used by navigators when filing flight plans involving winds which would interfere with actual flight.

The stability as well as the maneuverability of aircraft are dependent upon finding that "point" in the plane called the center of gravity. The loading of fuel and the pay load of the aircraft must be taken into account when figuring the center of gravity. As the aircraft's flight progresses, this "point" will have a tendency to shift and corrections will have to be made from time to time to make allowances for losses of weight en route.

Personnel concerned with catapult and arresting gear aboard aircraft carriers must also apply the Laws of Newton in order to compensate for short runways and small landing areas. The recoil mechanisms of some weapons also utilize these laws to a great advantage.

I. COMPOSITION OF FORCES

a. Meaning

(1) Parallelogram method

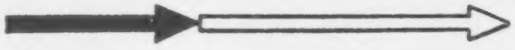
(2) Combination of forces

b. Resultant

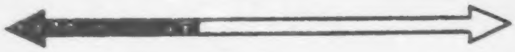
(I) Definition

(2) For forces acting:

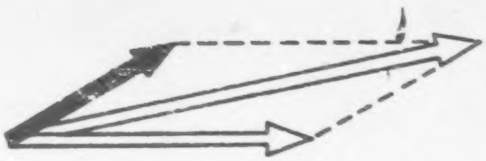
(a) Same direction



(b) Opposite direction



(c) Definite angle

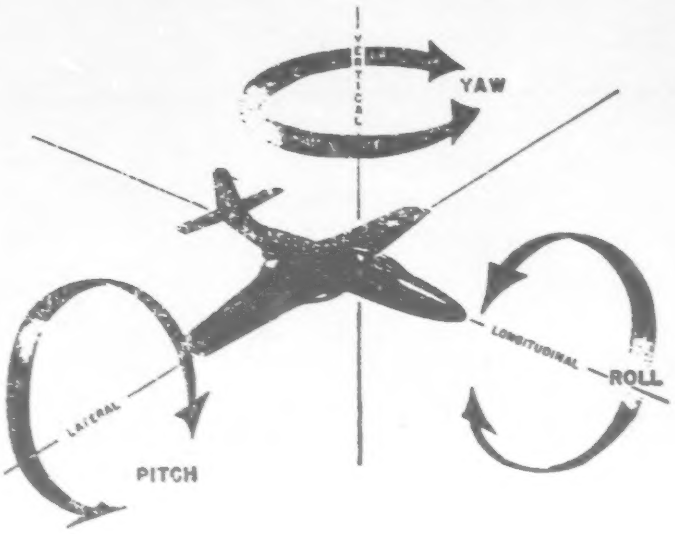


c. Application to aviation

2. CENTER OF GRAVITY

a. Meaning

b. Application to aviation

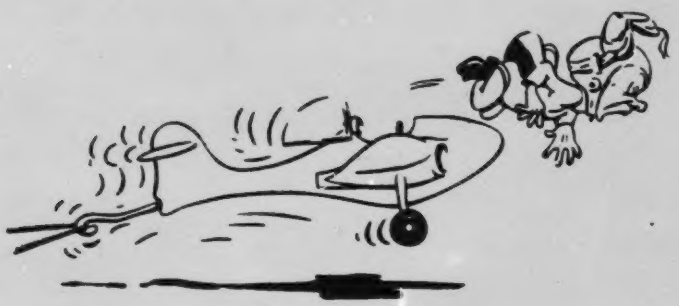

VERTICAL
YAW
LONGITUDINAL
ROLL
LATERAL
PITCH

3. NEWTON'S LAWS OF MOTION

a. Law of Inertia

(1) Statement of law

(2) Explanation of law



(3) Application to aviation

b. Law of Action and Reaction

(1) Statement of law

(2) Explanation of law

(3) Application to aviation

1. The force and direction in which an object moves when two or more forces act upon it is called:

2. Find the resultant force of a 6-pound force acting in a northeasterly direction and a 10 pound force acting in a southeasterly direction.

3. If a boat is capable of developing a speed of 12 knots in still water, find its speed if it moves:

   with a tide of 4 knots:

   against a tide of 4 knots:

   at right angles to a tide of 4 knots:

4. A force of 15 pounds is acting upon an object in an easterly direction, and another 15-pound force is acting on the object in a westerly direction. The resultant force will move in what direction?

5. Two equal forces are acting upon a body, one in a westerly direction, and the other in a northerly direction. The resultant force will show the body to be moving in what direction?

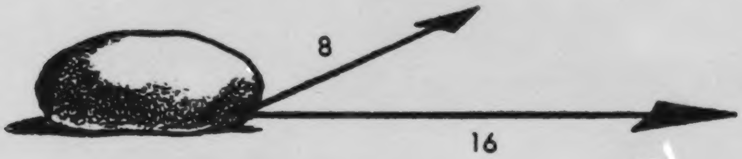
6. Newton's Law of Inertia states that a body ____________________ remains at rest and a body ________________ will continue in motion unless acted upon by ____.

7. Newton's Law of ________________ applies to the torque of a propeller and is offset in a single-engine aircraft by use of ____________________________.

8. Newton's Law of Action and Reaction is also used to explain __________ of weapons.

9. In an aircraft, the center of gravity is considered to be at that point where the intersection of ____________________________________ axis appears to occur.

10. In the sketch, a force of 8 pounds and another of 16 pounds are indicated as acting upon the body at the angle shown. Sketch in the resultant force.



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WHENEVER AN EXTERNAL PRESSURE IS APPLIED TO ANY CONFINED FLUID AT REST, THE PRESSURE IS INCREASED AT EVERY POINT IN THE FLUID BY THE AMOUNT OF THE EXTERNAL PRESSURE.

Blaise Pascal
1623 - 1662
French philosopher, mathematician
and scientist

PASCAL'S LAW

A generally accepted fact is that solids will transmit force. However, the fact that fluids will also transmit force is not so well known. This fact does exist and has been proved many times over. It is the underlying principle for many of our mechanical devices in aviation and everyday life.

For all practical purposes, fluids are non-compressible. This is the basis for the use of fluids in transmitting forces in such mechanical items as: hydraulic jacks, hydraulic brakes, air brakes, and other compression-type devices. Blaise Pascal, a French scientist, has been credited with that mathematical statement which is known as Pascal's Law. His law is based on a small force acting upon a small surface area transmitting a pressure which acts upon a large surface area and creates a large force. In applying this law, the fluid must be considered to be at rest and enclosed.

The previous lesson brought out the similarity as well as the primary difference that exists between force and pressure. Pascal's Law utilizes the principle that pressure upon an enclosed fluid is transmitted equally and without loss to all parts of the containing vessel and at right angles to the walls of the vessel. PRESSURE IS NOT AFFECTED BY THE SHAPE OF THE VESSEL WHICH CONTAINS IT. By properly applying Pascal's Law, forces may be transmitted to equalize a condition or multiplied to utilize a given force.

1. STATEMENT OF PASCAL'S LAW

2. EXPLANATION OF PASCAL'S LAW

    a. Fluid enclosed

    b. Pressure equal at all points

    c. Force transmitted

    d. Force multiplied

3. APPLICATION OF PASCAL'S LAW

    a. Hydraulic jack

        (1) Definition

        (2) Construction: The basic parts and their use are:

            (a) Vent

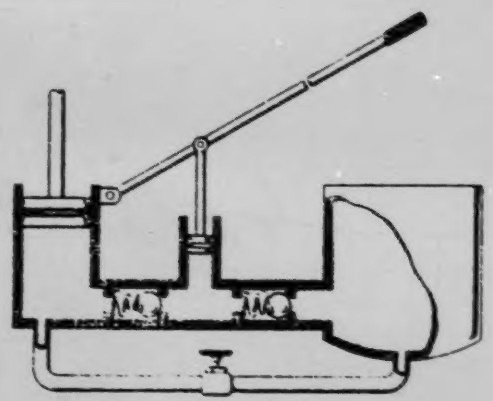
            (b) Reservoir

            (c) Check valves

            (d) Hand pump

            (e) Large piston

            (f) Shut-off valve



b. Aircraft Hydraulic System (incomplete)

(1) Explanation

(2) Construction: Essential parts and their use are:

(a) Vent

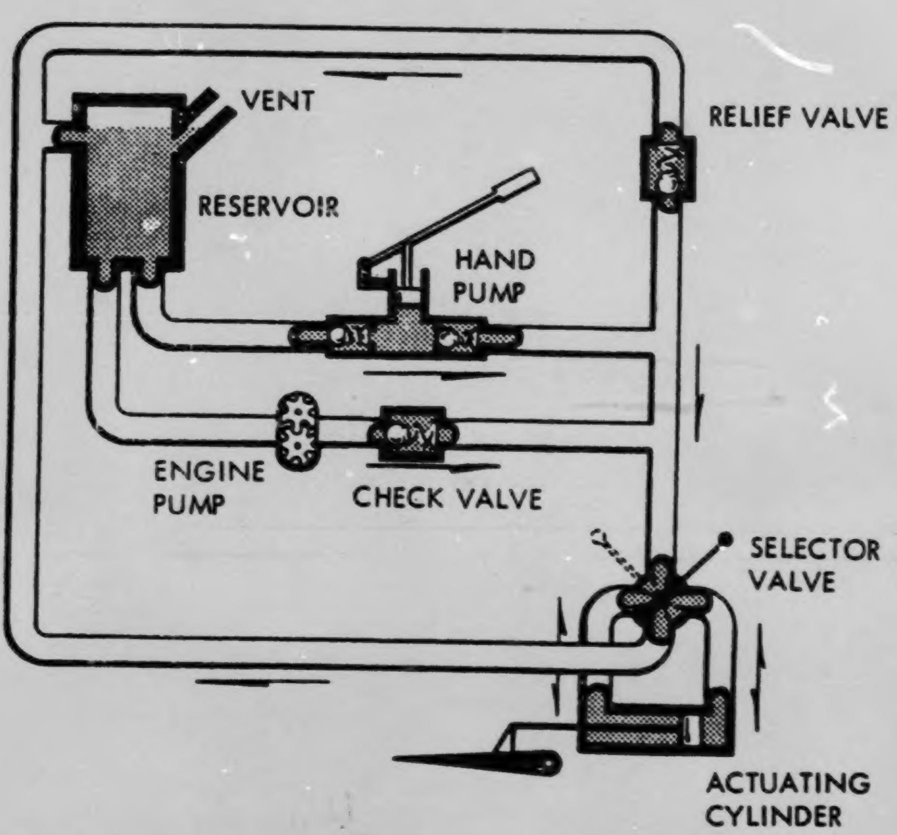
(b) Reservoir

(c) Check valves

(d) Hand pump or power pump

(e) Actuating cylinder

(f) Selector valve


VENT
RELIEF VALVE
RESERVOIR
HAND PUMP
ENGINE PUMP
CHECK VALVE
SELECTOR VALVE
ACTUATING CYLINDER

Work Sheet **PASCAL'S LAW**

1. Pascal's law states that ______________________ applied to an enclosed fluid, is transmitted ______________ and ________________ in all ______________.

2. Find the force needed on a small piston of a hydraulic jack, one square inch in area, to produce a force of two tons on the large piston, ten square inches in area.

3. Find the area of the large piston of a hydraulic jack needed to show a force of 10,000 pounds, when a force of 10 pounds is applied to the small piston having an area of one square inch.

4. Find the area of the small piston of a hydraulic jack when a force of 40 pounds on it will produce a force of 8 tons on the large piston, having an area of 20 square inches.

5. What should be the area of piston on a hydraulic elevator to permit it to lift 5 tons, if the available water pressure is 100 pounds per square inch?

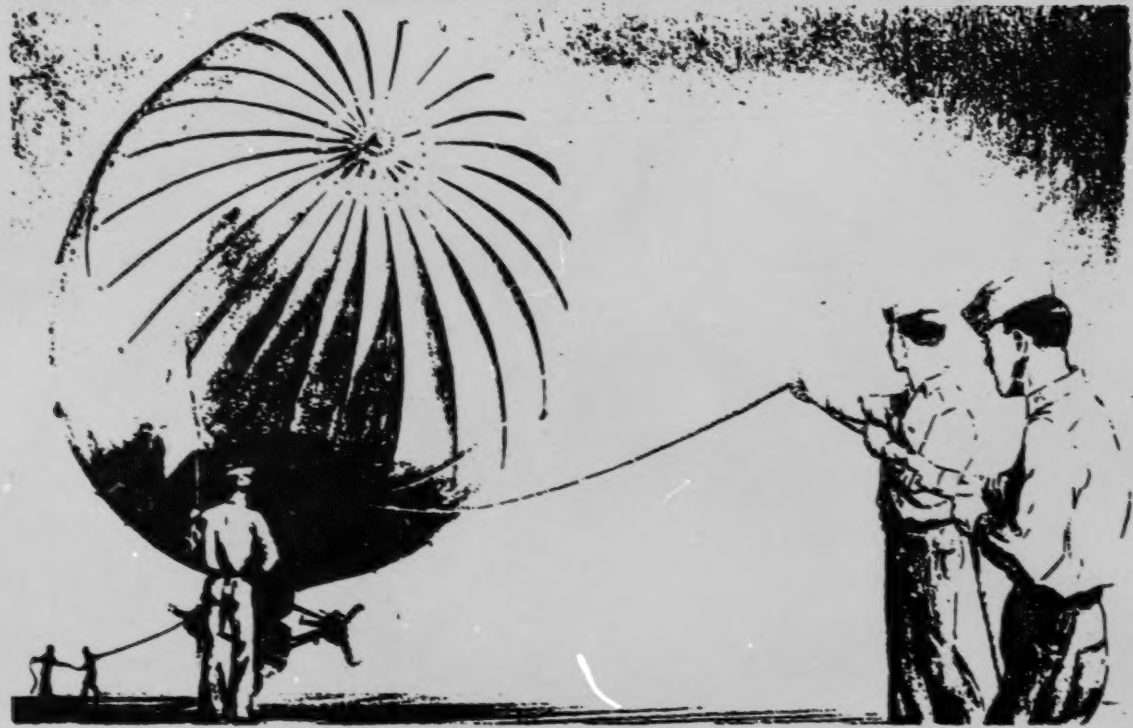
6. Find the force that must be applied to the hydraulic hand pump in the cockpit to lower a wing flap against a 2000 pound slipstream force, if the piston of the hand pump is one square inch in area and the piston of the actuating cylinder is 10 square inches in area.

7. Find the force needed on a small piston, whose area is 10 square inches, to produce a force of 10,000 pounds on the large piston, whose area is 50 square inches.

8. A diver goes down in salt water to a depth of 200 feet. Find the pressure in pounds per square inch that will be exerted upon his body.

9. Find the pressure in pounds per square inch acting upon an area of 10 square inches, if the force exerted is 150 pounds.

10. Using Pascal's Law, a force is ________________________ if the piston areas or strokes are equal but is ______________________ if they are unequal.



FORCE AND PRESSURE

The development of civilization and many of the mechanical devices so common to man today have resulted from his ability to harness the forces of nature. These forces are always present in some form of energy or matter such as solid or fluid (fluid including liquids as well as gases). A more lasting appreciation of the fundamentals of the physical world will be gained through knowledge of these forces and how they act.

Probably the most misunderstood fact in regard to FORCE and PRESSURE is the failure to understand the distinction that exists between a force and a pressure. By definition, these two words mean:

FORCE is the total pressure acting upon an object.

PRESSURE is the force per unit of area.

Another fallacy in working mathematical problems on force or pressure is trying to establish a difference when the action takes place beneath a solid or beneath a fluid. Strange as it may seem, the definitions given above apply in either case; however, the actual data needed to solve the problem may have to come from a different source.

Just what relationship force and pressure have to aviation will be covered in this lesson.

1. **BENEATH A SOLID:** Force and pressure are always present and easily recognizable when acting beneath a solid object.

a. FORCE

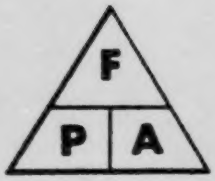
(1) Definition

(2) Units of Measurement

(3) Formula F = A x P

F =
A =
P =

(4) Problem



b. PRESSURE

(1) Definition

(2) Units of Measurement

(3) Formula P = F/A

P =
F =
A =

(4) Problem

2. BENEATH A FLUID

Force and pressure are present on the surface and beneath the surface of a fluid. They are harder to recognize when acting beneath a fluid.

a. FORCE

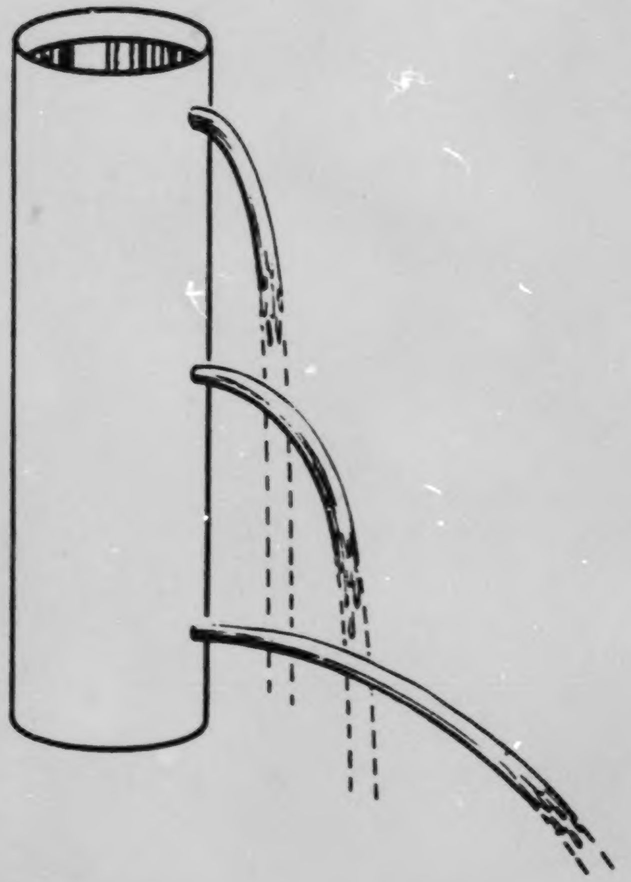
(1) Definition

(2) Units of Measurement

(3) Formula $F = A \times P$
$F = A \times D \times H$

F =
D =
H =

(4) Problem



b. PRESSURE

(1) Definition

(2) Units of Measurement

(3) Formula $P = F/A$
$P = D \times H$

P =
D =
H =

(4) Problem

1. A diver goes down to a depth of 150 feet in sea water (density of 64 pounds per cubic foot). Find the pressure on each square foot of his body.

2. A box 10 feet long, 8 feet wide, and 6 feet deep is full of fresh water (density of 62.5 pounds per cubic foot). Find the total force on the bottom of the box.

3. A man dives into sea water to a depth of 300 feet. Find the pressure on each square foot of his body.

4. A man weighing 185 pounds exerts how much force upon the deck?

5. Find the total force exerted upon the bottom of a tank of fresh water 5 feet deep, if the area of the bottom is 60 square feet.

6. A volcano is 13,760 feet high. Assuming the crater is full of molten lava with a density of 175 pounds per cubic foot, find the pressure at the bottom of the volcano.

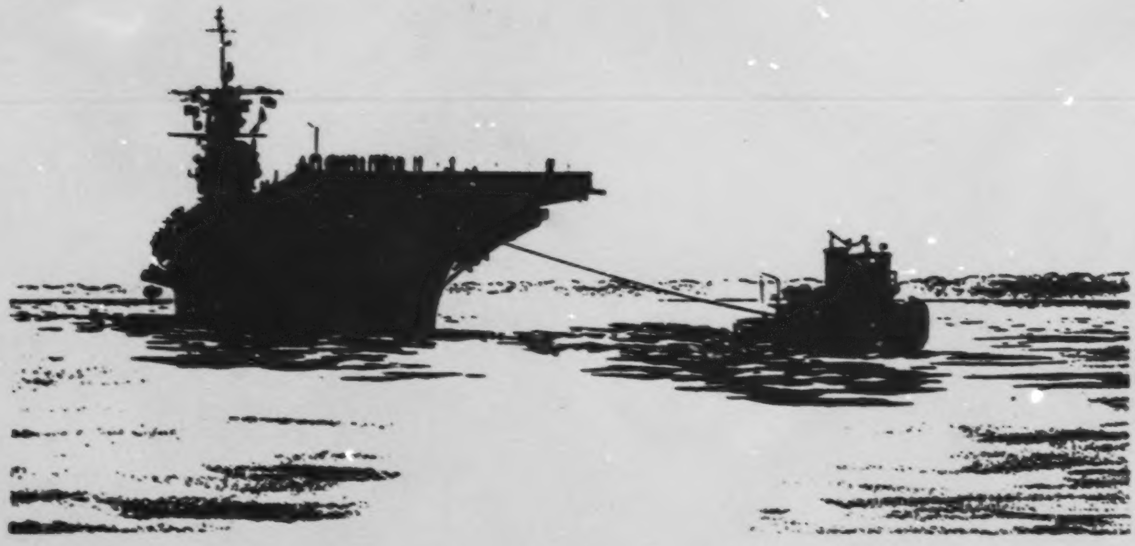
7. A box weighing 500 pounds is 6 feet long, 5 feet high, and 8 feet wide. Find the force exerted by the box on the deck.

8. Find the pressure exerted on the bottom of the box (in problem 7).

9. A box weighing 900 pounds has a bottom area of 200 square feet. Find the pressure that is exerted on each square foot of the bottom of the box.

10. The pressure at the point of a phonograph needle may amount to several tons per square inch. Since the reproducer head weighs only a small amount, explain how the above pressure is possible.

11. What would be the pressure on a phonograph needle if the reproducer head weighed .5 pounds and the contact area of the needle is .0001?



WORK AND POWER

In our study of force and motion, emphasis was placed on the relationship that exists between them. There are other relationships that involve force and motion and these relationships include work, power, and energy.

Energy is usually considered in terms of the two kinds -- kinetic and potential. Kinetic energy is energy already in motion or energy ready for immediate usage; potential energy is stored up energy for later usage or energy due to a position or condition of stress.

When we discuss work or power, we must consider the relationships of force, distance, and time. Of these three, time is the difference between work and power. There are great forces all around us, but unless they move through even a small distance, no work has been accomplished. If we give further consideration to the length of time such forces move, then we shall have power.

Opposition to work may normally be found in the form of gravity, inertia, and friction. Sometimes all three oppositions are at work. In most mathematical computations, such elements are not always considered, but in practical applications of the principles of work, power, and energy, they play a vital role in determining the efficiency of most machinery.

Historical and scientific experiments have provided a unit for measuring power in relationship to the amount of work an average workhorse can do in a specific length of time. Thus, today's machines are classified or rated according to their horsepower. It has been found that a man can produce at a rate of one horsepower for a short time.

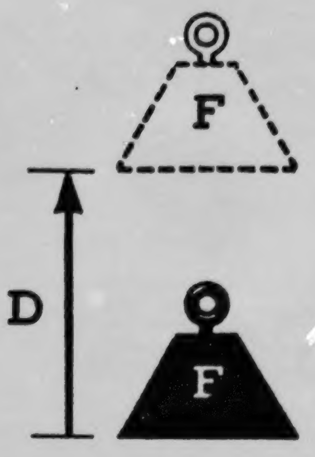
1. WORK

a. Definition

b. Explanation

c. Units of measurement

d. Formula $W = F \times D$



(1) Meaning of parts

W =
F =
D =

(2) Problem

2. POWER

a. Definition

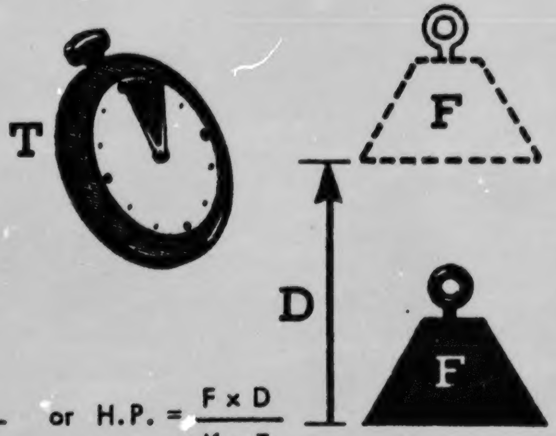
b. Explanation

c. Units of measurement

(1) Definition of horsepower

(2) Unit factor (K)

d. Formula $H.P. = \frac{W}{K \times T}$ or $H.P. = \frac{F \times D}{K \times T}$



(1) Meaning of parts

H.P. =
W =
T =
F =
D =
K =

(2) Problem

1. Work can be defined as the result of____________________________________.

2. The amount of work accomplished in lifting a ton weight up a vertical distance of 25 feet will be:

3. The amount of work performed when a force of 25 pounds is used to slide a 150 pound weight along the deck a distance of 10 feet will be:

4. Power implies that the work has been____________________________________.

5. Horsepower is the amount of________________an average__________________

   can do in____.

6. The amount of work done by a force of 75 pounds in pushing a 2-ton boat a distance of 6 feet from shore will be :

7. The horsepower required to accomplish the previous problem's work in 3 seconds will be:

8. The amount of work that an 8-horsepower engine can do in 2 minutes is:

9. An engine lifts 550 pounds through a vertical distance of one foot in one second. The horsepower needed to do this job will be :

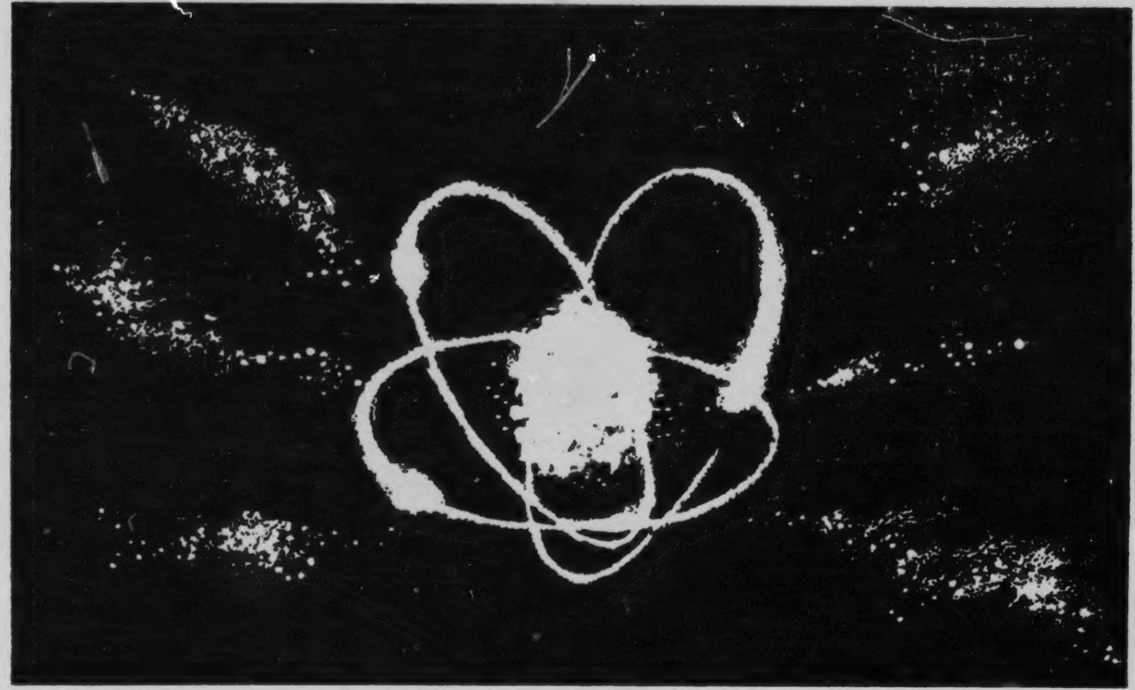
10. A 150-horsepower engine can do how much work in 5 seconds?

11. A hoist on a cargo plane lifts a one-ton weight a distance of 11 feet in 10 seconds. The amount of work done is:

12. The horsepower to accomplish the work for the previous problem, will be:

13. Kinetic energy is energy________________for use______________________.

14. Potential energy is energy________________for use______________________.



ATOMIC PROPERTIES

Benjamin Franklin's experiments with kite flying and electricity proved that an electrical current flows along a metal conductor. The direction in which it flowed was agreed on among the earlier scientists---from positive pole to negative pole on the basis that something with an excess (plus) could lose current to a deficiency (minus). Today scientists agree with this theory and speak of an excess of electrons moving to a point where there is known to be a deficiency of electrons. This more recent concept is closely associated with the electron theory of current flow.

To be able to explore and discuss the electron theory would require the knowledge of a nuclear physicist. To get a simple understanding of what makes up the theory requires a look into the properties of the atom. The illustrations which are used in this lesson are merely representations which have been chosen to assist in the discussion of atomic properties and are by no means fixed or unchangeable.

The atom has three basic parts: the electron, the proton, and the neutron. These three parts determine its charge, its atomic number, and its atomic weight. The charge may be negative when there is an excess of electrons or positive when there is a deficiency of electrons. The charge becomes neutral when there is an equal number of electrons and protons. The protons and neutrons will provide the major portion of the weight of the atom. A charged atom will obey the Law of Polarity in its attempt to reach a neutral state.

1. DEFINITION OF THE ATOM

2. STRUCTURE OF THE ATOM

a. Electron

    (1) Charge of electron
    (2) Weight of electron
    (3) Location of electron

b. Proton

    (1) Charge of proton
    (2) Weight of proton
    (3) Location of proton

c. Neutron

    (1) Charge of neutron
    (2) Weight of neutron
    (3) Location of neutron

3. CHARGE OF THE ATOM

a. Negative charge

b. Positive charge

c. Neutral state

4. ATOMIC NUMBER OF THE ATOM

a. Definition

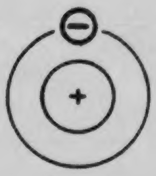
b. Explanation

5. ATOMIC WEIGHT OF THE ATOM

a. Definition

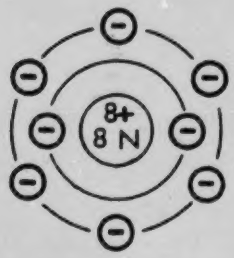
b. Explanation

6. ILLUSTRATIONS:



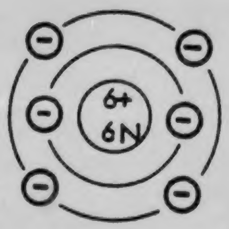
Hydrogen

Atomic No.__________
Atomic Wt.__________



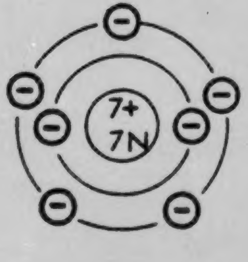
Oxygen

Atomic No.__________
Atomic Wt.__________



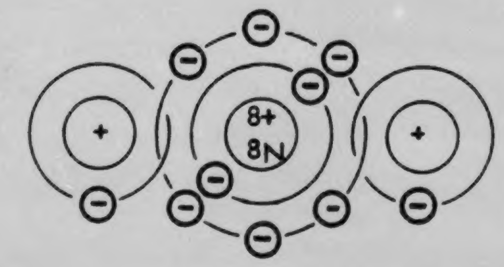
Carbon

Atomic No.__________
Atomic Wt.__________



Nitrogen

Atomic No.__________
Atomic Wt.__________



Water H_2O

Work Sheet **ATOMIC PROPERTIES**

1. The structure of an atom includes a ________________ made up of protons and neutrons and one or more orbit where ______________ travel.

2. The three major particles found in an atom are ____________________________, ____________________________, and ____________________________.

3. The weight of an atom is determined by the number of ____________________ and ___________________ located in the ____________________________.

4. The number of _________________ present in an atom which is in the neutral (normal or balanced) state will determine the atomic ______________________.

5. An excess of electrons will give the atom a _______________________ charge.

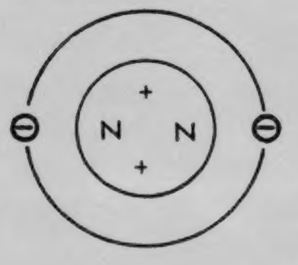
6. The ________________________ atom has no neutrons.

7. For an atom to be in the neutral (normal or balanced) state, there will have to be an equal number of ____________________ and ______________________.

8. The movable particle(s) of an atom are called ___________________________.

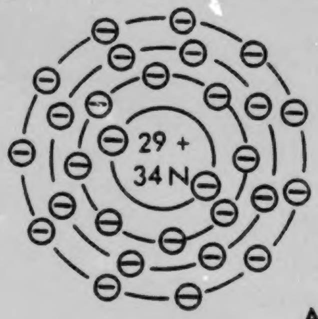
9. Electrons that are loosely bound to the nucleus of an atom are known as ____________________________.

10. Indicate the atomic number and atomic weight for each of the following:



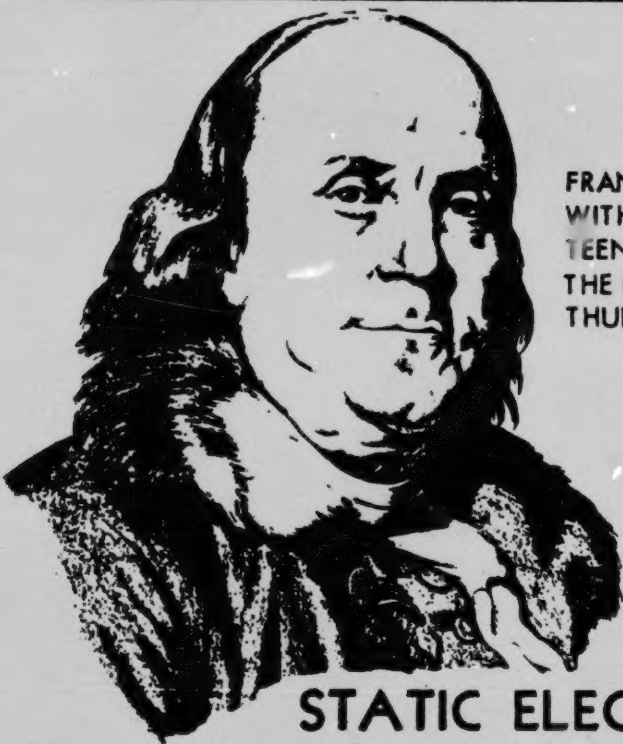
Helium

Atomic No. _____
Atomic Wt. _____



Copper

Atomic No. ____
Atomic Wt. ____



FRANKLIN'S FAMOUS DEMONSTRATION WITH KITE AND KEY IN THE EARLY SEVENTEEN HUNDREDS WAS EPOCH-MAKING IN THE FIELD OF SCIENCE. IT PROVED THAT THUNDERCLOUDS CARRIED ELECTRICITY

Benjamin Franklin
1706 - 1790
American statesman and scientist

STATIC ELECTRICITY

The electricity caused by friction (rubbing two different materials together) is known and classified as static electricity or electricity at rest. This type of electricity has been known for several thousand years but it has never had any practical use. Static electricity is always present in the form of a potential danger to cause fires or interference with radio transmissions.

During the last 200 years scientists, including Benjamin Franklin, have learned the relationship that exists between electricity and magnetism as well as the relationship between electricity and lightning which accompanies thunderstorms. From the various discoveries and experiments, methods have been developed to combat the electrical charge which results from static electricity building up in different equipment.

Many of us have experienced the shock resulting from combing our hair or sliding across the plastic seat covers of our car. These are simple examples of static electricity which afford amusement as well as surprise to the experimenter. While a sufficient spark to light a fire may not be generated, such sparks are powerful enough to be felt. It is definite proof that static electricity does exist.

In aviation, there are many examples of static electricity charges building up during the flight of an aircraft. Such buildups might occur while taking off, while landing, taxiing, or during refueling. Safety measures in the form of grounding wires, bonding wires, static discharger tires, and the like must be installed to offset these charges.

1. DEFINITION OF STATIC ELECTRICITY

2. SOURCE OF STATIC ELECTRICITY

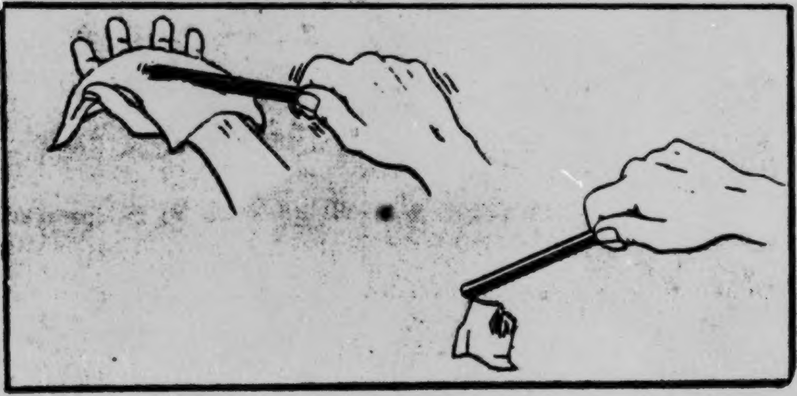
3. STATIC CHARGE

a. Positive charge

b. Negative charge

c. Illustration

(1) Assume the rod and cloth are both in a neutral state.
(Each atom has an equal number of electrons and protons.)
(2) Attempt to pick up bits of paper with either one.
(Note that neither will attract the paper while in this state.)
(3) Rub the rod and cloth together to produce friction.
(Some electrons will pass from one to the other.)
(4) Attempt to pick up bits of paper with either one.
(Note the rod attracts the paper but the cloth will not.)
(5) This is conclusive proof that the rod has been charged.
(The cloth has also been charged but due to material it can not be as concentrated as on the rod.)



4. APPLICATION TO AVIATION: PRIMARILY USED AS SAFETY DEVICES

a. Grounding wire

b. Bonding wire

c. Static discharger

Work Sheet **STATIC ELECTRICITY**

1. Friction produces ____________ electricity by causing ____________ to move.

2. Electricity at rest is called ______________________________.

3. The result of rubbing a glass rod with a piece of silk cloth indicates that a charge has been built up on ______________________________.

4. A ____________ charge is produced by an excess of ____________.

5. A static charge is built up during refueling as a result of friction caused by the ______________________________.

6. Static charge on an airplane may result from contact with ______________________ during flight.

7. The static discharger tire affords a path for the flow of ____________ to the ____________ during ____________________.

8. During flight, two normally insulated parts of the aircraft will have a ______________ wire connection to equalize the static charges.

9. During refueling, a ____________ wire will connect the aircraft to the ____________ to equalize the static charges that build up.

10. Radio interference in an aircraft caused by build-up of static charge can be prevented by use of ______________________________.

11. All the means which are used to prevent danger from fire or explosion due to static charges primarily afford a path for the ____________ in order to ____________ the static charge which builds up.

12. A static discharger wick is attached to ____________ and affords a path for the flow of excess ____________.

13. An aileron would be connected to a wing by a ____________ wire.

CURRENT ELECTRICITY

The lesson on "Static Electricity" pointed out the potential danger which accompanies the build-up of excess electrons due to friction. The lesson on "Magnetism" covered the Law of Polarity which governs the action when two bodies with like or unlike charges are brought close together. This lesson on "Current Electricity" ties both of these ideas into the Electron Theory of Current Flow and brings out the useful applications of their effect in terms of electricity.

The electron theory explaining current flow (electricity in motion) is substantiated by four cardinal points, namely: (1) negative electricity exists in the form of tiny particles called electrons; (2) the action of electric charges is due to an excess or deficiency of these electrons; (3) an electric current in a metallic conductor consists of moving electrons; and (4) difference in properties of the chemical elements is largely due to the number and arrangement of the electrons present.

Current electricity (which is electricity in motion) depends upon electromotive force (emf), current flow, and resistance, all of which have a definite mathematical relationship to each other. Each has its own units to measure its value in a mathematical problem as well as in an electrical circuit. There are certain influencing factors which increase one or the other of these units, while at the same time they are still able to retain their relationship within a particular circuit.

1. STATEMENT OF ELECTRON THEORY (CURRENT ELECTRICITY)

2. ELECTROMOTIVE FORCE (emf)

   a. Definition

   b. Source

   c. Measurement (unit and instrument)

3. CURRENT FLOW

   a. Definition

   b. Source (direction of flow)

   c. Measurement (unit and instrument)

4. RESISTANCE

   a. Definition

   b. Factors affecting

      (1) Material of conductor

      (2) Cross-sectional area

      (3) Length of conductor

      (4) Temperature effect

   c. Measurement (unit and instrument)

5. APPLICATION TO AVIATION

Work Sheet CURRENT ELECTRICITY

1. The Electron Theory explains current as the flow ____________________.

2. Electrons are ______________ charged particles present in ____________.

3. Current electricity depends upon ______________________________.

4. Electromotive force (emf) is that ______________ which tends to move the ________________ through a conductor.

5. According to the Electron Theory of Current Flow, electrons flow from ________ ____________ to ____________ within an electrical circuit.

6. Emf exists in chemical form in ________________________________ or is created mechanically by ________________________________.

7. Current flow is measured in __________; emf is measured in __________; resistance is measured in __________.

8. The opposition to current flow within an electrical circuit is known as ________ ____.

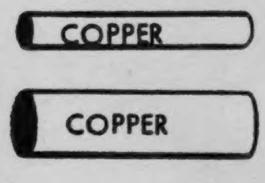
9. The factors affecting resistance within a circuit are: __________________ ____.

10. Poor conductors are considered as very effective ____________________.

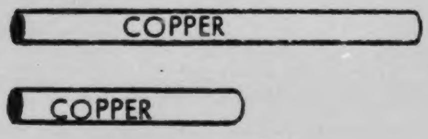
11. Ammeters are connected in a circuit in ______________, while voltmeters are connected in ________________ and ohmmeters have their own voltage.

12. Compare the resistance effect between the following pairs of conductors:

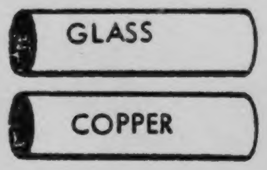
a. Areas



b. Lengths

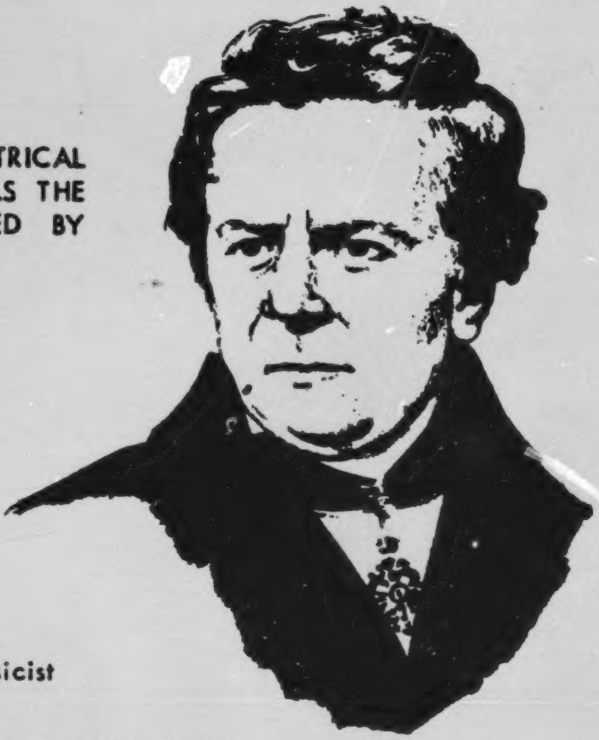


c. Heat applied to:



THE INTENSITY OF THE ELECTRICAL CURRENT IN A CIRCUIT EQUALS THE ELECTROMOTIVE FORCE DIVIDED BY THE RESISTANCE.

$$I = \frac{E}{R}$$



Georg Simon Ohm
1787 - 1854
German mathematician and physicist

OHM'S LAW

In 1826, Georg Simon Ohm, a German physicist, proved that there was a mathematical relationship between electromotive force, current flow, and resistance for any particular electrical circuit. Since that date, OHM'S LAW has been the basis for many electrical problems. Simply stated, Ohm's Law says: "ONE VOLT will push ONE AMPERE through ONE OHM."

In applying Ohm's Law, two of the values needed must be known; then a mathematical problem will provide the missing value. Many people find that the "Magic Circle" is a useful aid in setting up mathematical problems to be solved using Ohm's Law. For purposes of brevity, the letter "E" represents electromotive force, the letter "I" represents the intensity of current flow, and the letter "R" represents the resistance encountered.

The practical application of Ohm's Law in solving electrical circuit problems has many and varied uses. For the pure mathematical problem, the resistance of the wire in the circuit will be disregarded. However, when applying the law to an actual problem involving the electrical circuit of an aircraft, the length, the material, and the cross-sectional area of the wire used will affect the total resistance of the circuit in question and will have to be included in the problem. In many cases a variable resistor, called a rheostat, is included in a circuit to correct or adjust the resistance caused by these factors.

1. Ohm's Law states ______________________________.

2. Two things that will determine current flow within a simple circuit are

   ____________________ and __________________________.

3. An increase in resistance will ____________________ the current flow in a simple circuit.

4. Find the emf of a circuit having an internal resistance of 15 ohms and drawing 8 amperes of current.

5. Find the resistance of a heater filament from a radio tube which draws 0.15 ampere of current in a circuit having a 45-volt emf source.

6. Find the current drawn by an electric light bulb whose filament has a resistance of 16 ohms and operates in a circuit having 120 volts emf.

7. Find the emf required to operate a heater circuit of a radio tube which has a resistance of 42 ohms and draws 0.3 ampere of current.

8. A dynamometer is a device for converting low-voltage D.C. to high-voltage D.C. Find the current a dynamometer will draw if it has an internal resistance of 4.8 ohms and operates from a 12-volt emf source.

9. An electric heater operates from a house line (120 volts) and draws 5 amperes of current. Find the resistance of the heater coil.

10. Find the resistance of an electric drill operating on 110 volts and drawing 2 amperes of current.

11. Using a battery emf of 8 volts, find the current that would flow through a 1000-ohm resistor.

12. A motor operating on 120 volts draws 0.5 ampere. Find its resistance.

13. A pilot light draws 0.5 ampere and has a resistance of 12.6 ohms. Find the amount of emf necessary to operate this light.

14. Find the resistance of a resistor, if a 25-volt battery causes 0.09 ampere of current to flow through the resistor.

15. The purpose of a rheostat in a circuit is to ________________________.

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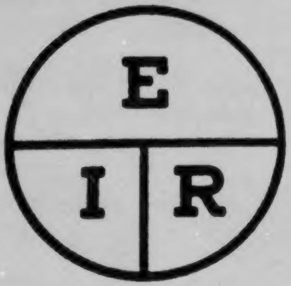
1. DEFINITION OF OHM'S LAW

2. FORMULA $E = I \times R$



a. Meaning of parts

E =
I =
R =

b. Problems

(1) To find electromotive force

(2) To find current flow

(3) To find resistance

3. APPLICATION TO AVIATION

a. Mathematical

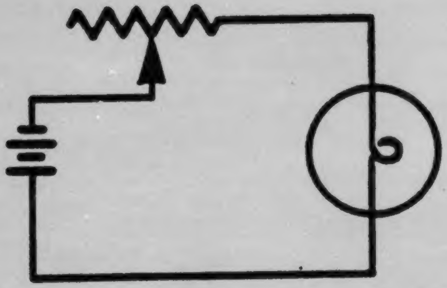
b. Practical (rheostat)

(1) Definition

(2) Construction

(3) Principle of operation

(4) Use in aviation



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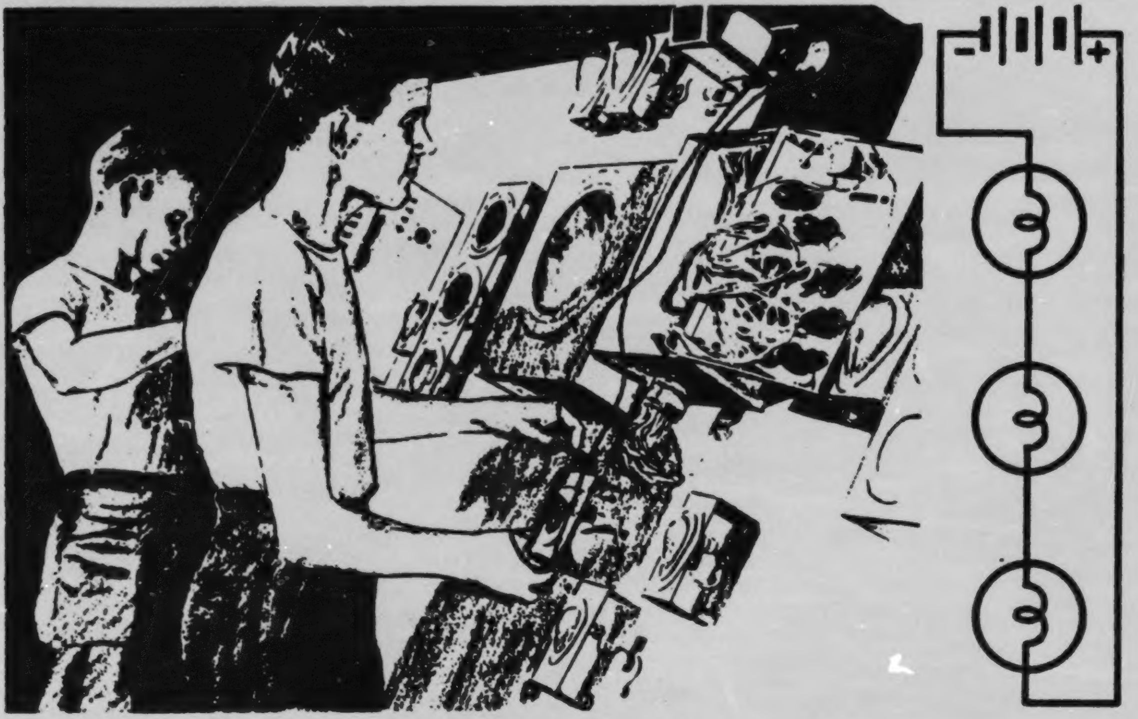


SERIES CIRCUITS

An electrical circuit includes a path for current flow (flow of electrons) under a pressure of an electromotive force (battery or generator for supply) and the path itself will offer the resistance (wire and devices which make up the circuit). A simple circuit can be formed by merely connecting a wire from one terminal of a battery to the other terminal (called a closed circuit or complete path). When other resistors (devices) are put into the circuit, it takes on the characteristics of one of the two basic circuits, namely: series circuit or parallel circuit, or some combination of these.

The series circuit has the identifying characteristic of a SINGLE PATH for current flow. The flow of electrons must pass from one device to another in making the complete circuit from emf source NEGATIVE terminal back to the emf source POSITIVE terminal. Thus the number of electrons passing any given point in the circuit will be the same as at any other point in the circuit. The greatest disadvantage of a series circuit is that when one device of the circuit fails, the circuit breaks down because the path is broken.

Mathematical formulas will show the current flow to be constant within the circuit; the TOTAL emf will be the SUM of the individual emf's and the TOTAL (equivalent) resistance will be the SUM of all resistances.

1. DEFINITION OF A SERIES CIRCUIT

2. APPLICATION OF OHM'S LAW

a. Electromotive force (emf)

(1) Voltage drop

(2) Formula $E_t = E_1 + E_2 + E_3$

b. Current flow

(1) Factors determining

(2) Formula $I_t = I_1 = I_2 = I_3$

c. Resistance (total)

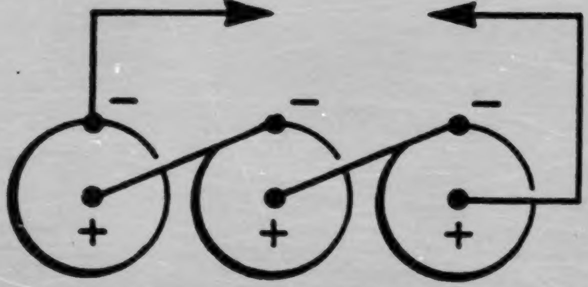
(1) Amount

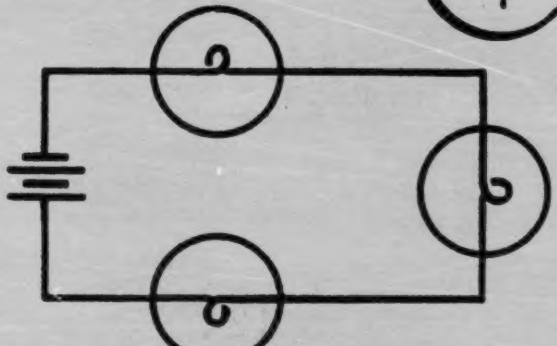
(2) Formula $R_t = R_1 + R_2 + R_3$

3. APPLICATION TO AVIATION

a. Series circuits

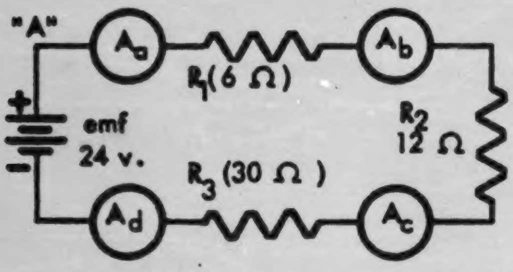
b. Series cell grouping

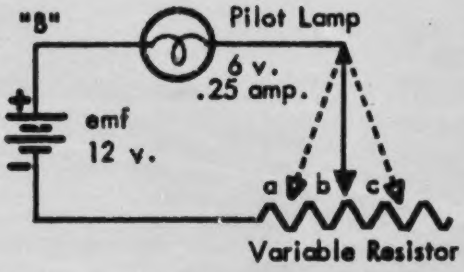




Work Sheet **SERIES CIRCUITS**

1. The principal characteristic of a series circuit is ________________________ for current flow.





2. The equivalent (total) resistance of the circuit shown in diagram "A" will be:

3. The current flow through the resistors in diagram " A" will be:

4. The ammeter readings for diagram "A" will read: a.________ b.________ c.________ d.________. This is because ____.

5. The voltage drop in diagram "A" across the following points will be:

a to b______; b to c______; c to d______; a to c______; a to d______; b to d______.

6. Diagram "A" is a ________________ circuit composed ________________ resistors and having ________________________________ for current flow.

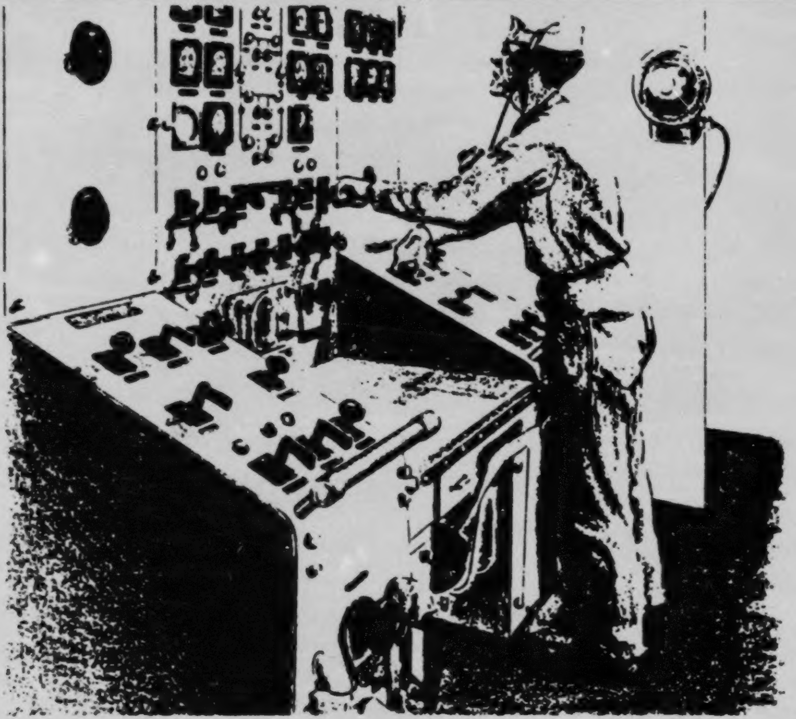
7. The variable resistor in diagram "B" is called ________________________.

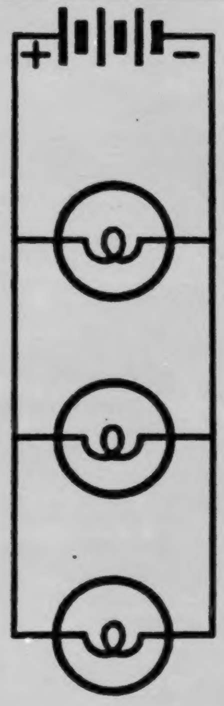
8. To make the lamp in diagram "B" burn brighter, the movable arm will have to be moved towards point______; this will ____________________ resistance.

9. The resistance of the pilot light in diagram "B" is ________________________.

10. In diagram "B", for the lamp to burn normally, the resistance between points a and b should be: ____.

11. The main purpose of a series cell grouping is to conserve ____________________ while increasing ________________ and ________________ internal resistance.





PARALLEL CIRCUITS

In contrast to the series circuit, the parallel circuit affords a great many more and varied uses in electrical equipment and especially in aviation. It will permit a single constant source of electromotive force to operate many individual devices, each requiring a different current flow. It has a major advantage of permitting the circuit to continue to operate,even if one or more of the individual devices fails.

The principal characteristic of a PARALLEL CIRCUIT is that it has SEVERAL PATHS for the current flow. Thus, when the flow is blocked by one path, the current will seek another path. The greatest flow will be through that one resistor which has the least resistance. The EQUIVALENT (total) resistance of the circuit will be LESS THAN the resistance of the smallest resistor.

Mathematical formulas will show the electromotive force (emf) to be constant across any resistor in a parallel circuit. The total current flow equals the SUM of the current flow through each resistor, and the EQUIVALENT (total) resistance to be found by using Ohm's Law or the RECIPROCAL FORMULA.

The applications of electrical circuits often combine the advantages of both the series and parallel circuits into a more complex circuit which is beyond the scope of this course and will be studied later.

1. DEFINITION OF A PARALLEL CIRCUIT

2. APPLICATION OF OHM'S LAW

   a. Electromotive force (emf)

      (1) Voltage drop

      (2) Formula $E_t = E_1 = E_2 = E_3$

   b. Current flow

      (1) Factors determining

      (2) Formula $I_t = I_1 + I_2 + I_3$

   c. Resistance (equivalent)

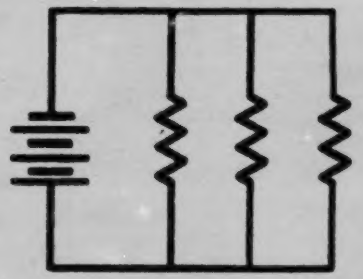
      (1) Amount

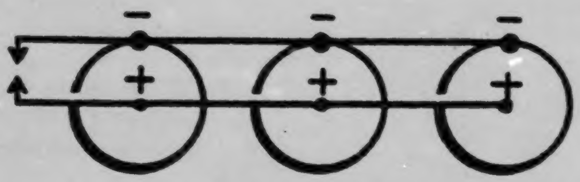
      (2) Formula (reciprocal) $\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

3. APPLICATION TO AVIATION

   a. Parallel circuits

   b. Parallel cell grouping

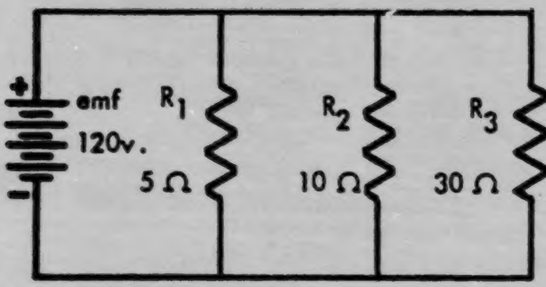




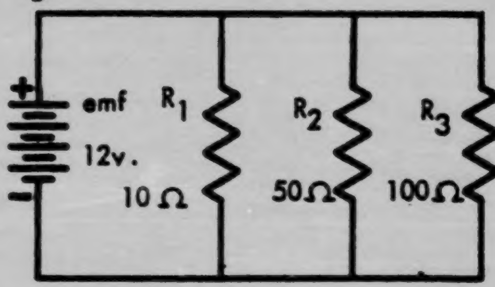
Work Sheet **PARALLEL CIRCUITS**

1. The principal characteristic of a parallel circuit is ______________ for current flow.

"A"



"B"



2. The total voltage drop in the circuit of diagram "A" will be: ______________

3. The equivalent (total) resistance of the circuit of diagram "A" will be: __________

4. The current flow through the individual resistors in diagram "A" will be:

R_1 ______________, R_2 ______________, R_3 ______________.

5. The equivalent (total) resistance of the circuit in diagram "B" is : ______________.

6. The voltage drop across the 10-ohm resistor in diagram "B" is: ______________.

7. The current flow through each resistor in diagram "B" will be: R_1 ______________,

R_2 ______________, R_3 ______________.

8. If one of the resistors in diagram "A" or "B" were to fail or be taken out, the equivalent (total) resistance of the circuit would ______________.

9. Find the equivalent resistance of a parallel circuit having resistors whose ratings are: 12 ohms, 6 ohms, and 8 ohms.

10. A voltmeter is always connected in ______________, while an ammeter is always connected in ______________.

11. The main purpose of a parallel cell grouping is to conserve ______________ while increasing ______________ and ______________ internal resistance.

A LINE OF MAGNETIC FORCE IS A LINE WHICH INDICATES AT ITS EVERY POINT THE DIRECTION IN WHICH A NORTH-SEEKING POLE IS URGED BY THE ATTRACTIONS AND REPULSIONS OF ALL THE POLES IN THE NEIGHBORHOOD.

Michael Faraday
1791 - 1867
English physicist and chemist

MAGNETISM

This study of magnetism will be the first portion of the course devoted to electrical physics. It will be found that the theories, laws, and principles developed in the lessons that follow will sometimes be difficult to define and equally difficult to understand. It must be remembered, however, that scientists, physicists, and mathematicians have rigorously tested these principles and theories and that they have been found to be sufficiently accurate. It will be necessary from time to time to mention supporting items which will have to be accepted without further discussion in order to clarify certain main points in this study of physics.

Most of us have witnessed the properties of magnetism at work and have accepted them with a brief explanation. While many of the properties may seem a bit mystical, they are closely associated with electricity and of course electricity is a field that has not been completely explored. We are concerned primarily with the theories that have practical application in our work in aviation and in particular the properties that are associated with magnetism and how they affect materials used in the manufacture of electrical devices.

Magnetism cannot be defined precisely. It is, however, based upon two assumptions that have been accepted in the world of science. These assumptions are the Molecular Theory and the Law of Polarity. Generally speaking, we have heard magnetism referred to as the power of a magnet; the quality to which magnetic force is due; and possibly more often, as flux or lines of force.

The Molecular Theory of magnetism considers that each molecule of any substance has a definite north and south pole which reacts to magnetic force according to the Law of Polarity. The Law of Polarity simply states that like poles repel and unlike poles attract. This law causes flux patterns to form around magnets which indicate lines of force flowing definitely from north to south outside the magnet and never crossing each other.

All matter is considered to have magnetic properties to some extent. For purposes of classification, substances have been separated into two general classes --- MAGNETIC and NON-MAGNETIC. Those substances which are strongly affected (attracted) by magnets are called magnetic substances, while those which are not noticeably affected (attracted or repelled) by magnets are called non-magnetic substances.

Natural magnets are lodestones or pieces of iron ore having the power to attract other pieces of iron. Artificial magnets are often made by man from magnetic substances. These artificial magnets fall into two basic classes: PERMANENT, made from materials hard to magnetize but which retain their magnetism for long periods of time; and TEMPORARY, made from materials easy to magnetize but which lose their magnetism after short periods of time. Most magnets are composed of iron, nickel, and cobalt, and various alloys of these metals. Other materials are often included for some particular property or purpose.

The properties of magnetism (or magnetic lines of force) are many and varied. Among the more important properties are: concentration, permeability, and demagnetization. The strength of a magnetic field is important when determining the power of the magnet and is indicated by the number of lines of force at any given point, with the greatest concentration at the poles. The ability of a substance to conduct lines of force will identify magnetic substances from non-magnetic substances. The act of losing or weakening the power of a magnet can be accomplished by striking, heating, or passing the magnet through an alternating current (AC) field. Magnetic power may be transferred from permanent magnets to temporary magnets as with the case of a bar of soft iron laid across the ends of a horseshoe magnet, and the final result of having the magnetic force acting through the soft iron bar.

Simple experiments can be conducted by the student using a "dime store" magnet and some iron filings. These items will illustrate the flux pattern set up around the magnet. It will also be possible to partially and temporarily magnetize nails or bits of iron metal.

Later lessons in this half of the course will emphasize the practical use and application of magnets, magnetic fields, magnetic force, lines of force, and their role in the theories of electricity.

1. DEFINITION

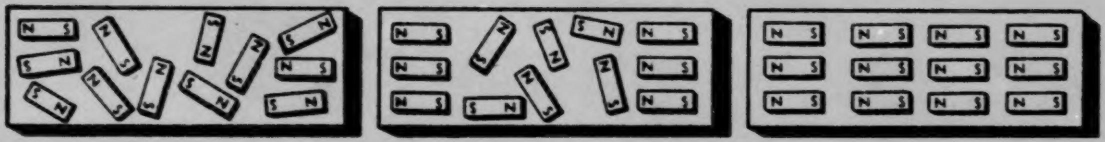
2. MOLECULAR THEORY OF MAGNETISM:

Accepted theory in field of science based on two assumptions.

a. All molecules of a magnetic substance are considered to be individual tiny magnets.

b. These tiny magnets obey the Law of Magnetic Poles (Law of Polarity).

c. Explanation

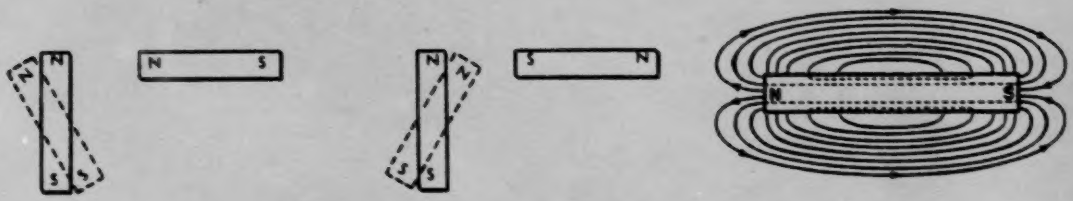


3. LAW OF MAGNETIC POLES (LAW OF POLARITY)

a. Like magnetic poles repel

b. Unlike magnetic poles attract

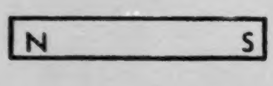
c. Flux pattern

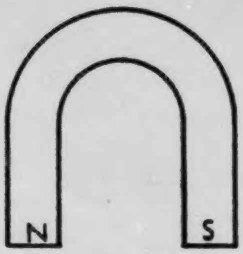


4. KINDS OF MAGNETS
    - a. Natural magnets
    - b. Artificial magnets
        - (1) Permanent
        - (2) Temporary

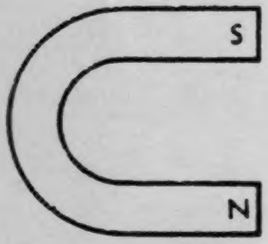
5. CLASSIFICATION OF MATERIALS
    - a. Magnetic materials
    - b. Non-magnetic materials

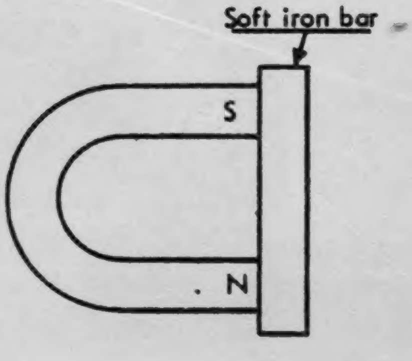
6. PROPERTIES OF MAGNETISM
    - a. Lines of force
    - b. Concentration
    - c. Intensity
    - d. Saturation





- e. Permeability
- f. Transference





- g. Demagnetization
- h. Retentivity
- i. Reluctance

1. The Molecular Theory of Magnetism states that each ____________________ of a ________________ is considered to have ____________________ which react to ____.

2. The Law of Polarity states that like ________________________ and unlike ________________________ each other when brought close together.

3. Lines of force flow from ______________ to ________________ outside a magnet and never ____.

4. Two sources of magnetism are: ______________ and ________________.

5. Permanent magnets are made from materials ____________ to magnetize, but which ____________ their magnetic power for ___________ periods of time.

6. Temporary magnets are often made from ______________________________.

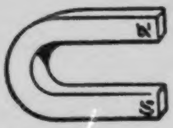
7. Magnetic materials is the classification of materials which includes those materials ________________ by magnetic force.

8. All materials are affected by magnetic force. Those which show the __________ by magnetic force are classified as non-magnetic.

9. The concentration of magnetic lines of force about a magnet will be __________ __________ at the poles of the magnet.

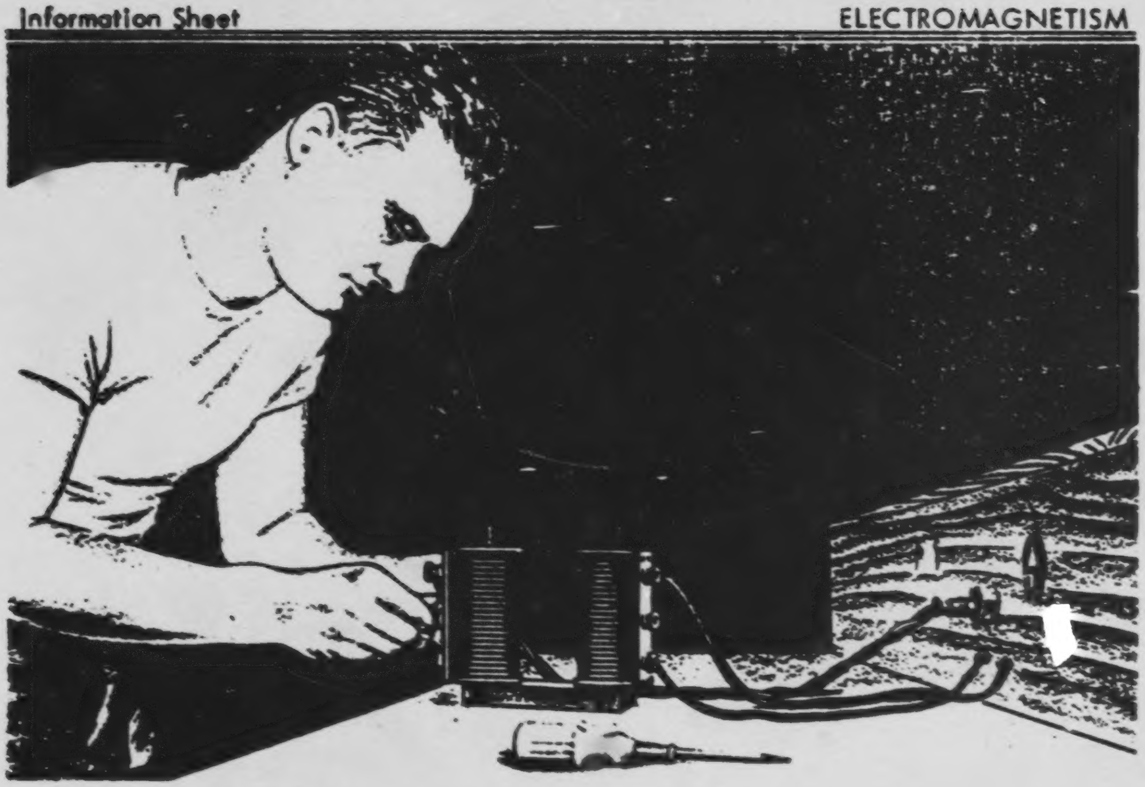
10. Demagnetization of a magnet can be accomplished by: ____________________ ____.

11. Sketch the magnetic field or flux pattern around the following:



WOOD

IRON



ELECTROMAGNETISM

Several of the preceding lessons on electrical physics have discussed separate topics, such as : Magnetism, Atomic Properties, Electrical Theories, and Electrical Circuits. In these lessons, it was learned that a CURRENT FLOW is caused by an ELECTROMOTIVE FORCE. That ELECTRONS possess charges which obey the Law of Polarity --- that magnetism and electricity are closely related.

A Danish physicist named Oerstad proved in 1819 that a magnetic field is set up around a conductor as a result of a flow of current through the conductor. This effect is known as ELECTROMAGNETISM. From this effect have come many developments in the realm of electricity and devices which rely on electricity as a source of energy. The aircraft used today by civilian and armed forces depend on these principles to a great extent for their operation and especially for their communication.

The pattern (FLUX) of this magnetic field which is set up around the metal conductor will depend upon: the shape of the conductor; the number of conductors present; the material of which the conductors are constructed; and the amount of current flowing through the conductors. For quick checks of the relationship existing between the direction of current flow and the magnetic field, the LEFT-HAND RULE can be applied. Among the applications used are: electromagnets, relay switch, solenoids, motors, and generators.

1. DEFINITION OF ELECTROMAGNETISM

2. ELECTROMAGNETIC EFFECT AROUND CONDUCTORS

   a. Single straight conductors: Single wire or metal bar.

      (1) Current flow

      (2) Magnetic field

      (3) Left-hand rule test

   b. Multiple straight conductors: Several wires or metal bars.

      (1) Current flow direction same for all conductors

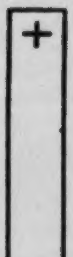
      (2) Current flow direction opposite for some conductors

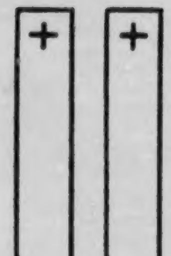
   c. Coiled conductors: Coiled wire or SOLENOID.

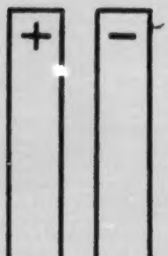
      (1) Current flow

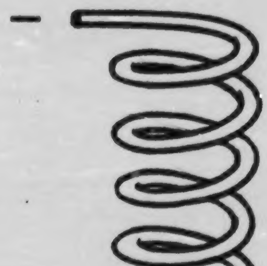
      (2) Magnetic field

      (3) Left-hand rule test



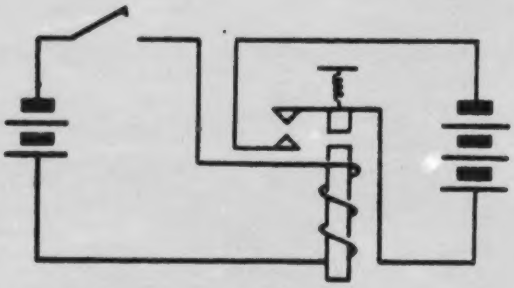


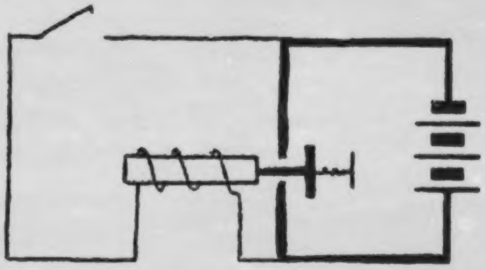




3. APPLICATION OF ELECTROMAGNETISM

- a. Electromagnet
  - (1) Definition
  - (2) Factors influencing strength
  - (3) Polarity
  - (4) Use in aviation
- b. Relay switch
  - (1) Definition
  - (2) Factors influencing use
  - (3) Principle of operation
- c. Solenoid relay switch
  - (1) Definition
  - (2) Factors influencing use
  - (3) Principle of operation



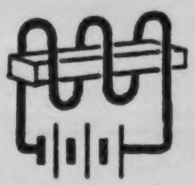


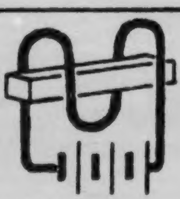
Work Sheet **ELECTROMAGNETISM**

1. Electromagnetism is the ____________ produced by ____________ ____________ through a ____________.

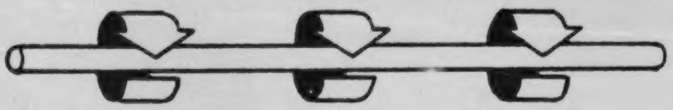
2. A coil of wire carrying a current is called ____________.

3. Assuming the current and the core are the same in the electromagnets pictured below, which one is weaker? ________ Why? ____________.





4. Which direction is the current flowing in the conductor? Use arrow and (+) (-) signs.

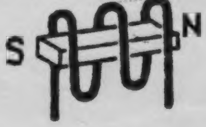


5. Current flow within a conductor is from ____________ to ____________.

6. Factors affecting the strength of an electromagnet are: ____________
____________.

7. The magnetism that remains in a material after the magnetizing force is called the
____________.

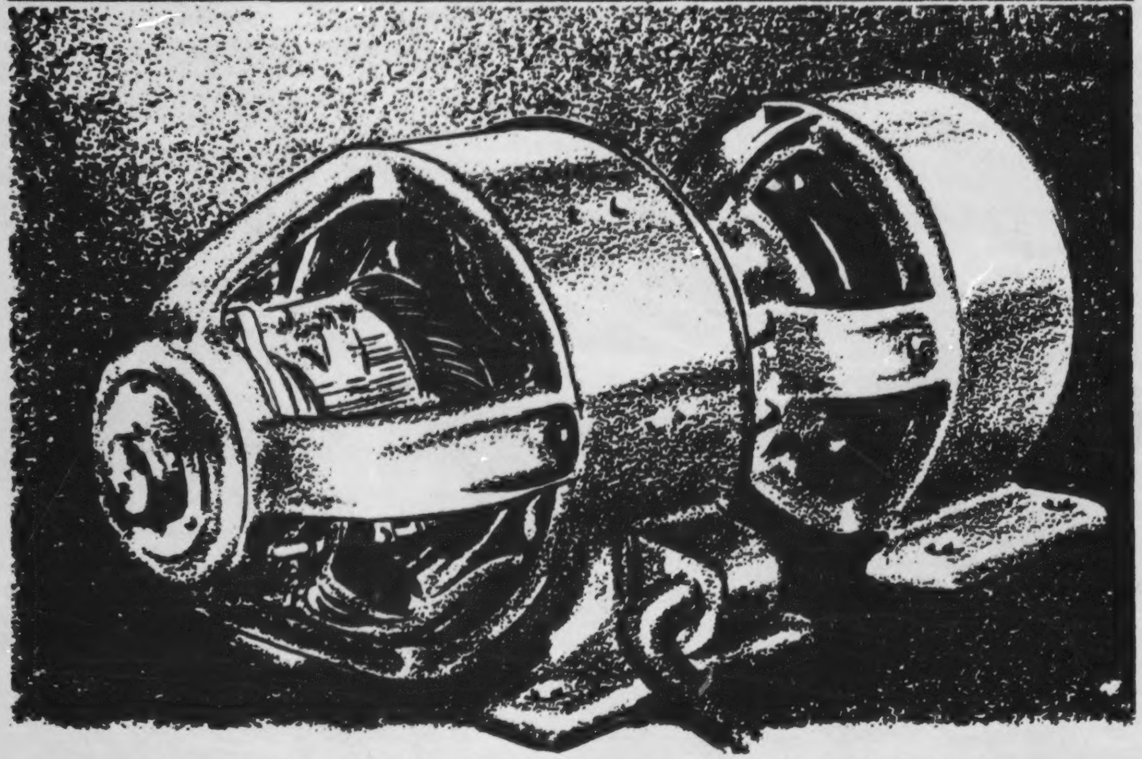
8. Indicate the current direction necessary to create the poles shown:



9. The relay and the solenoid relay switches are used to ____________ control electrical circuits.

10. The ____________ switch uses a stationary iron core, while the ____________ switch relies on a movable iron core.

11. What part does the electromagnet play in relay switch operations?



ELECTROMAGNETIC INDUCTION

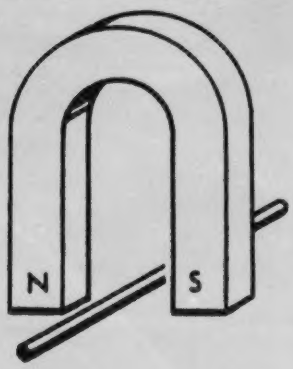
About the same time that Oerstad was discovering that a current flow through a conductor would set up a magnetic field about the conductor, an English scientist, Faraday, conducted experiments to see if a magnetic field about a conductor could INDUCE a current flow.

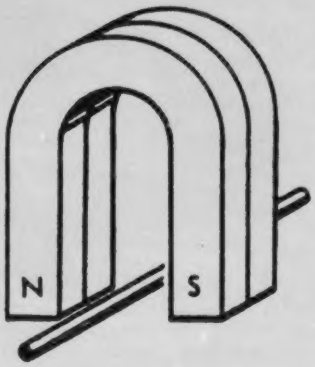
These two experiments, and the discoveries that followed, opened a new field known as ELECTROMAGNETIC INDUCTION. Since then, applications have been developed (some simple and many complex) which affect electricity in aviation. Among the more common applications are: motors, generators, transformers, and magnets, all operated on electrical power and applying the principles of electromagnetic induction.

The factors needed to induce an electromotive force or a current flow in a conductor are: a magnetic field, a metal conductor, and some relative motion between these two. The primary difference between inducing an emf or inducing a current flow will be an OPEN or a CLOSED circuit. A CLOSED CIRCUIT IS NECESSARY BEFORE A CURRENT FLOW CAN BE INDUCED.

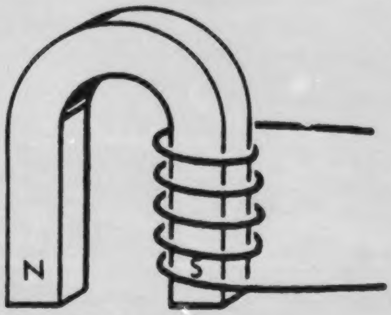
Several factors influence the strength of the induced emf or the induced current flow, namely: strength of the magnetic field; speed of the relative motion; number of coils of wire in the conductor; and the angle of the relative motion.

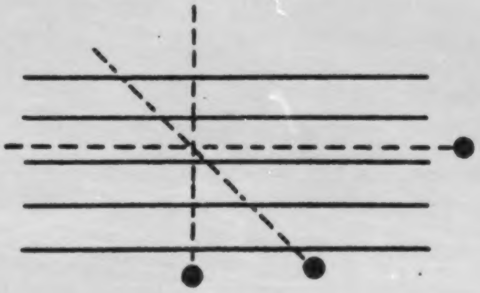
1. INDUCED ELECTROMOTIVE FORCE
   - a. Definition
   - b. Factors needed
     - (1) Magnetic field
     - (2) Conductor
     - (3) Relative motion
   - c. Factors affecting strength
     - (1) Strength of magnetic field
     - (2) Speed of relative motion
     - (3) Number of coils in conductor
     - (4) Angle of relative motion





2. INDUCED CURRENT FLOW
   - a. Definition
   - b. Factors needed
     - (1) Magnetic field
     - (2) Conductor
     - (3) Relative motion
   - c. Factors affecting strength
     - (1) Strength of magnetic field
     - (2) Speed of relative motion
     - (3) Number of coils in conductor
     - (4) Angle of relative motion





1. Electromagnetic induction is the result of passing a ____________________ through a ____________________.

2. To induce a current flow, ____________________ circuit is required.

3. Factors needed to induce emf are: ____________________ ____________________.

4. The four factors affecting the strength of an induced current flow are:

5. When a __________ is passed through the lines of force formed by the horseshoe magnet, an ____________________ is induced in the conductor.

6. A double magnet will ____________________ the induced current flow.

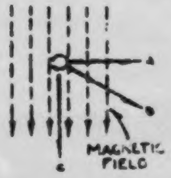
7. A coiled conductor will have ____________________ induced emf than a ____________________ conductor.

8. In drawing "A" below, indicate the direction of movement of the metal conductor through the lines of magnetic force that will produce the greatest emf.

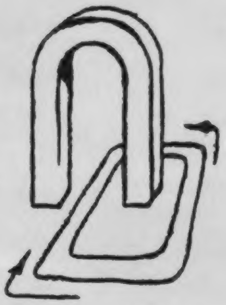
9. In drawing "B" below, would it be possible to indicate the magnetic poles with certainty? ____________________ WHY? ____________________.

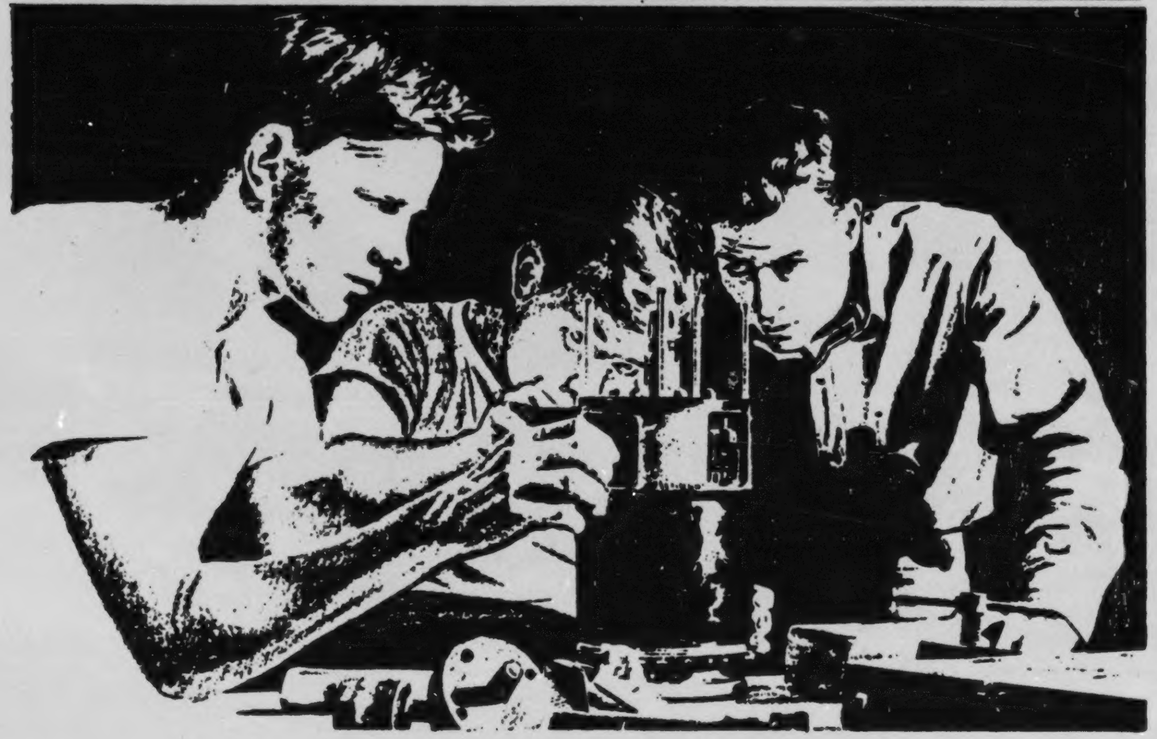
10. In drawing "B" below, if the left-hand pole was labeled north, and the direction of current flow was indicated by the arrows, then the conductor would be moving in which direction?

A



B





D.C. GENERATOR AND D.C. MOTOR THEORY

All the topics covered in the latter portion of this course have dealt with that part of physics referred to as ELECTRICAL PHYSICS. The main purpose of these topics, principles, laws, and theories has been to point out the usefulness of electrical energy in the development of machines and other devices which permit man to do MORE work in LESS time and with LESS effort.

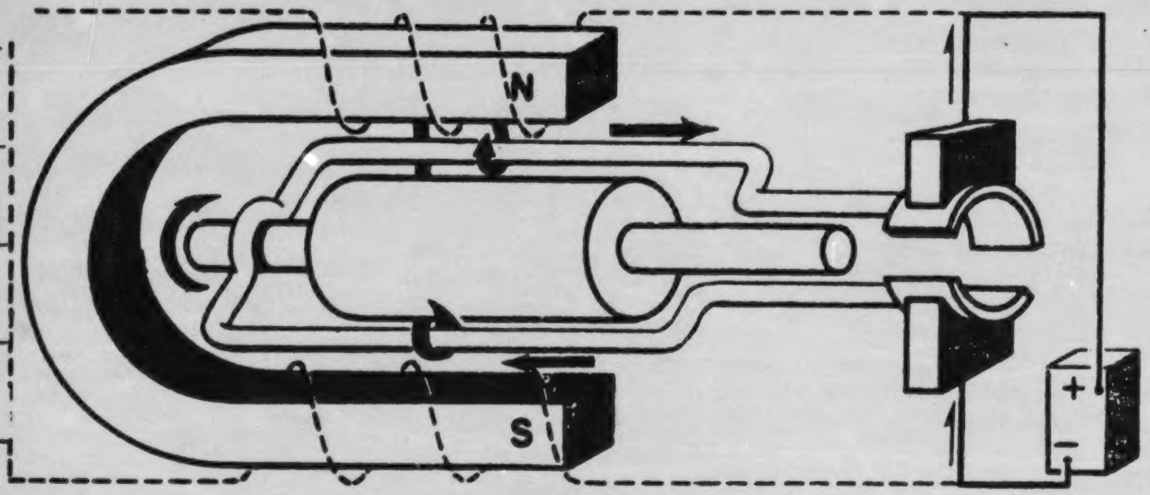
This lesson on the THEORY OF ELECTRICAL MOTORS AND GENERATORS is only one of the thousands of applications of the material covered by electrical physics. The use of electrical devices in aviation has become the problem of every man and applies to all ratings. Further study will be accomplished in the "A" Schools and the squadrons.

The electrical generator and motor operate on the same principle --- that of electromagnetic induction. They are constructed of the same four basic parts, namely: field magnets, armature, commutator, and brushes. The role of their parts will be different due to their primary use. The GENERATOR converts MECHANICAL energy into ELECTRICAL energy, while the MOTOR converts ELECTRICAL energy into MECHANICAL energy.

This lesson emphasizes the usefulness of all the topics that have made up this portion of the physics course.

I. DIRECT CURRENT (D.C.) GENERATOR

- a. Definition
- b. Principle of operation
- c. Basic construction
  - (1) Field magnets
  - (2) Armature
  - (3) Commutator
  - (4) Brushes
- d. Application to aviation



2. DIRECT CURRENT (D.C.) MOTOR

   a. Definition

   b. Principle of operation

      (1) Attraction -- repulsion theory

      (2) Conductor in a magnetic field theory

   c. Basic construction

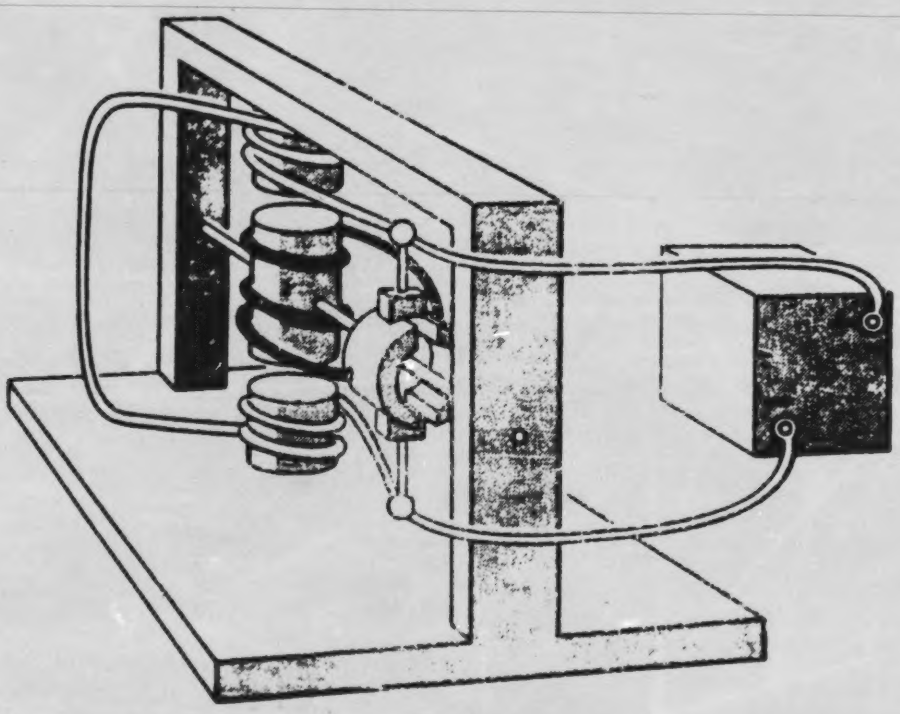
      (1) Field magnets

      (2) Armature

      (3) Commutator

      (4) Brushes

   d. Application to aviation



Work Sheet

D.C. GENERATOR AND D.C. MOTOR THEORY

1. A direct current generator converts __________________ energy into __________________ energy.

2. A direct current generator operates on the principle of __________________.

3. The four parts necessary to construct a direct current generator are:

4. The armature on a D.C. generator produces __________________ current.

5. The commutator on a D.C. generator changes __________________.

6. Generators are __________________ driven from the aircraft power plant.

7. A direct current motor converts __________________ energy into __________________ energy.

8. A direct current motor operates on the principle of __________________ __________________.

9. The four parts necessary to construct a direct current motor are:

10. The armature of a D.C. motor produces __________________ current.

11. The commutator on a D.C. motor changes __________________.

12. Motors are __________________ driven from the aircraft power plant.

13. Motors furnish __________________ power or energy to __________________.

14. Generators furnish __________________ power or energy to __________________.

PROGRAMMED INSTRUCTION

2-5

PRINCIPLES OF ELECTRICITY

Aviation Training Division
USCG - AR&SC - Elizabeth City, N. C.

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FOREWORD

This programmed text was prepared for use in the 3ABR42231 instructional system. The material contained herein has been validated using thirty-seven 42010 students enrolled in the 3ABR42231 course. Ninety percent of the students taking this text surpassed the criterion called for in the approved lesson objective. The average student required (1) hoursand (50) minutes to complete the text.

OBJECTIVE

After having completed this program, you will be able to explain:

1. The theory of magnetism.
2. How the magnetic effect is produced.
3. The application of laws of magnetism to coils and conductors.
4. Principles of electromagnetic induction.
5. The principle of Ohm's law.
6. The generation of AC and DC.

Standard of Performance:

Minimum acceptable performance will be achieved by attaining at least 70% on the criterion test.

INSTRUCTIONS

This program presents information is small steps called "frames." After reading each frame, you are expected to respond by supplying a word or words to complete some statements, choose either true or false, select the correct answer, or match some terms to their proper meaning. Use a piece of paper or card as a mask to cover the printed materials. Slide the paper or mask down the page until you expose the top of the slashes (////////////). One small step is now exposed. Read the materialppresented, select your response to the question, and indicate your response in this package. After you respond to the question, slide the mask down and compare your answer with the one given in the program. If you are correct, go on to the next frame. If your answer is wrong, read the frame again.

August 1969

Frame 1

Electric current must be controlled in a circuit in order to be useful. At this point, probably for most of you, current is nothing more than an unseen force which causes bulbs to light up, or as quite a few of you may have experienced, an unseen force which caused you discomfort through a shock. Only one of these effects is useful.

An important property of electricity is its ability to create a magnetic effect. Whenever current flows through a conductor (wire), a magnetic effect or force is produced. This magnetic force exists in the area surrounding the conductor. It is this magnetic force which contributes to the usefulness of electricity. If it were not for this magnetic property, such devices as motors, radios, radar, etc, would not work. Therefore, before you can understand how electricity works you must first learn something about magnetism.

//////////////////////

No Response Required

Frame 2

Magnetic force is an invisible force which exists in the space that surrounds a magnet and is capable of attracting iron or steel. Electrical force is invisible, as is the force of gravity; but the "effects" of electricity and gravity are visible and observable. The effects of magnetism are also observable. Two things can always be known about any force: (1) the direction in which it is acting, and (2) its strength.

Supply the missing word or words in the following statements.

1. Magnetism is a force which makes it possible for magnets to ________________ pieces of iron or steel.

2. The power that attracts small bits of iron or steel to the end of a magnet is called ___________ ____________.

3. The force which causes the needle of a compass to turn toward the north is also a _____________ _____________.

////////////////////////

1. attract 2. magnetic force 3. magnetic force

Page 2, Frame 3

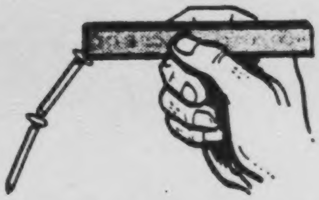
Magnets can be made from pieces of iron or steel by an artificial means and these are called artificial magnets. Most of the magnets with which you are familiar, such as bar magnets, horseshoe magnets, and compass needles, are artificial magnets. These artificial magnets can be further divided into two classes: permanent magnets and temporary magnets (electromagnets). Electromagnets, as you will find, are used in relays, solenoids, transformers, etc, and are created by passing current through a coil of wire wrapped around a soft iron core.

////////////////////

No Reponse Required

Frame 4

Pieces of iron or steel brought into contact with a magnet will become magnetized. The process of magnetizing a piece of iron or steel by bringing it into contact with a magnet is called "magnetic induction." The magnet exerting the magnetic force is called an "inducing magnet."



From the terms listed in the left hand column below select the word or words needed to complete the statements in the right hand column.

1. magnetic induction
2. magnetized
3. inducing magnet
4. temporary magnet
5. electromagnet
6. permanent magnet
7. magnetic force

a. If the steel blade of a screwdriver is placed across the ends of a magnet the blade will become ____________________.

b. The process by which the screwdriver became magnetized by bringing it into contact with the magnet is called ____________ ______________.

c. The magnet which exerted the magnetic force on the screwdriver is called the __________ __________

//////////////////////

a. magnetized b. magnetic induction c. inducing magnet

Frame 5

After an object becomes magnetized, it may lose its magnetism as soon as it is separated from the inducing magnet, or it may remain magnetized for a long time. The substance (material) of which the magnetized object is made determines how long it will remain magnetized.

If the object is made of soft iron, it will retain its magnetism for only as long as it remains in contact with the inducing magnet. Any magnet that loses its magnetism rapidly is called a temporary magnet.

If the object, which is magnetized, is made of hard steel rather than a softer iron alloy, it will retain its magnetism for a longer period of time after being separated from the inducing magnet. Any magnet that holds its magnetism for a long period of time is called a permanent magnet.

Supply the missing word or words in the following statement.

A magnet made of hard steel would be a ________________ magnet, whereas a magnet made of soft iron would be a ________________ magnet.

////////////////////

permanent - temporary

Frame 6

The ability of a magnetic material to remain magnetized is called "retentivity." Steel, which can remain magnetized for a long time, is said to have a high retentivity. Materials such as soft iron, which lose their magnetism very rapidly, have a low retentivity.

Complete the following statement.

________________ is the ability of a magnet to hold magnetism.

////////////////////

Retentivity

Frame 7

The magnetic force retained by a substance after its removal from the magnetizing force is called "residual magnetism." If a steel bar has been magnetized, the magnetic force which it holds is its residual magnetism

Supply the missing word or words in the following statement.

The actual magnetism which a magnet retains is ________________.

//////////////////////

residual magnetism

Frame 8

At this point several new words have been introduced. Very likely, we should take another look at these terms. Check your understanding of the terms by matching them with their proper meaning.

TERMS	MEANING
1. _____ magnetic induction	a. The ability of a material to hold magnetism.
2. _____ residual magnetism	b. A magnet used to make another magnet.
3. _____ retentivity	c. The magnetism which a magnet can hold.
4. _____ inducing magnet	d. The process by which magnets are made.

//////////////////////

1. d 2. c 3. a 4. b

Frame 9

So far, the only magnetic material we have mentioned that can be used for permanent magnets is hard steel. In recent years many alloys of iron have been developed for making permanent magnets. One of the best is called alnico----a combination of iron with aluminum, nickel, and cobalt. Since alnico makes a good permanent magnet it naturally has a very high retentivity and can hold a large amount of residual magnetism.

Select true or false for the following statement.

If a bar of alnico becomes magnetized it will be an electromagnet. _____

//////////////////////

False

8

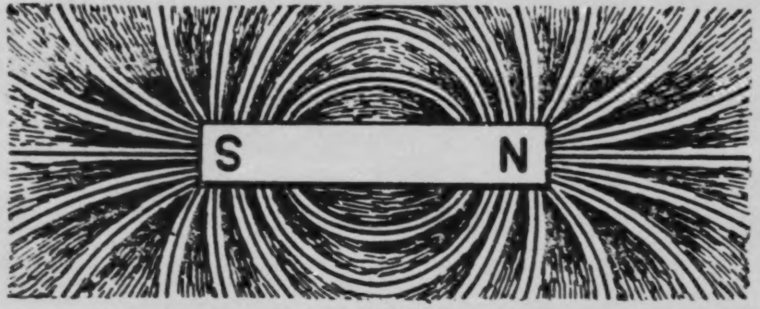
Frame 10

It is not necessary for an object to be in direct contact with a magnet in order to be influenced by it. If a north compass needle is placed near a bar magnet, it will turn toward the south pole of the magnet.

This magnetic force is strongest close to the magnet, but if the magnet is a strong one its effects can be felt for some distance.

The space surrounding a magnet in which the magnetic field exists, is called the "magnetic field." Since magnetic force is invisible, the magnetic field around a magnet is also invisible. However, we can see the effect of a magnetic field if we sprinkle iron filings on a piece of paper and then place it over a magnet. The iron filings arrange themselves in a very definite pattern because of the magnetic force of the magnet. The filings will take the shape of the magnetic field which surrounds the magnet.

The magnetic force of the magnet causes the iron filings to form themselves into lines, which circle the magnet. These are called "lines of force" or "flux lines."



Choose the word or words from the left column which correctly completes the statements listed on the right.

a. lines of force
b. magnetic field
c. magnetic force

1. Every magnet is surrounded by a __________ __________.
2. A magnetic field is made up of magnetic ______________ __ ________________.

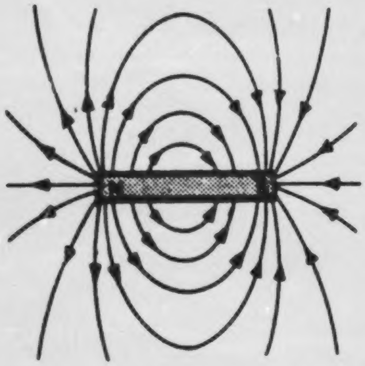
//////////////////////

1. magnetic field   2. lines (of) force

Frame 11

The magnetic field itself is sometimes called the "magnetic flux," that is the lines of force (flux) which surround the magnet. The ends of the bar magnet where the magnetic force is greatest, are called the "poles." The north seeking pole is referred to as the north pole and is represented by the symbol "N." The pole opposite the north seeking pole is called the south seeking pole, represented by the symbol "S."

A magnetic field is shown in the illustration. Notice the small arrowheads drawn on the lines of force. These arrows show the direction of the lines of force to be from the north pole of the magnet around to the south pole.



Is the following statement TRUE or FALSE?

Lines of force leave the north pole of the magnet. ________

//////////////////////

TRUE

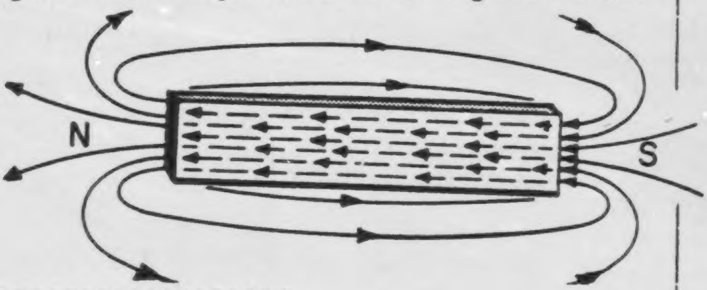
Frame 12

The lines of force inside the magnet also have direction. The direction of the lines of force inside the magnet is from the south pole to the north pole.

Each line of force leaves the magnet at the north pole, returns to the magnet at the south pole, and returns finally to the north pole.

Study the accompanying diagram and complete the following statement.

The lines of force move from the ________ pole to the ________ pole inside the magnet.

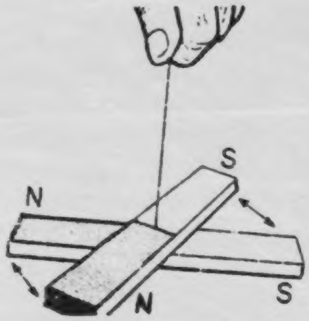


//////////////////////

south north

Frame 13

Two magnets also exert a magnetic force upon each other. If the north pole of one magnet is brought close to the north pole of another magnet, the north pole of one will turn away from the north pole of the other magnet. The south poles of the two magnets will also repel each other just as the north poles do. (Refer to the illustration) Lines of force pointing in the same direction always repel each other. Because of this mutually repelling force between lines of force, the lines of force never cross one another in a magnetic field. They tend to remain as far apart as possible. This fact causes the magnetic field around a magnet to expand and spread so that it covers a wider area than it would otherwise cover.



Is the following statement TRUE or FALSE?

_____ Lines of force never cross one another, and the magnetic field tends to spread and cover a large area because a mutual repelling force exists between the lines of force.

//////////////////////

TRUE

Frame 14

Lines of force, in addition to repelling one another, are always attracted to the south pole of a magnet. Because of this attraction, lines of force always try to take the shortest path from the north pole to the south pole (externally).

Supply the missing word in the following statement.

Lines of force always tend to take the ____________ path through the external magnetic circuit.

//////////////////////

shortest

Frame 15

There are two forces which act upon flux lines (lines of force). One is the mutually repellant force that causes them to try to spread out as far away from one another as possible. The other is the force of attraction that they have for the south pole of the magnet, that is as they travel externally from the north pole to the south pole, causing them to try to take the shortest path to the south pole. These two opposing forces account for the lines of force that are formed around the magnet.

//////////////////////

No Response Required

Frame 16

The two opposing forces acting upon the lines of force cause the lines of force to behave as if they were elastic bands stretched out in the field of the magnet. Because of this, if the magnetic force decreases, the lines of force will tend to collapse toward the magnet. If the magnetic field is increased, the lines of force will expand.

Is the following statement TRUE or FALSE?

The greater the strength of the magnet, the farther out into space surrounding the magnet its magnetic force will extend. ________

//////////////////////

TRUE

Frame 17

When the strength of a magnet is increased, the number of lines of force in the magnetic field will also increase. This increased number of lines of force cause all the lines in the magnetic field to be pushed closer together. When magnetic strength increases, the magnetic field expands and, also becomes more dense.

Complete the following statement.

The strength of a magnet can be measured by the density of the flux in its ______________ __________.

//////////////////////

magnetic field

Frame 18

You learned previously that retentivity is the ability of a substance to retain its magnetism after it is removed from a magnetizing force. The retentivity of a substance is actually due to the resistance of the molecules in the substance to change their direction. In soft iron the molecules can change direction easily. For this reason, when the magnetizing force is removed, the molecules almost immediately lose their alignment; therefore, the iron loses its magnetism.

Is the following statement TRUE or FALSE?

If soft iron has molecules that easily change direction it will have a very high retentivity. ______

//////////////////////

FALSE

151

Frame 19

Substances that are highly retentive also tend to be hard to magnetize because it is extremely difficult to change the direction of the molecules within them. The term that refers to the opposition of a substance to becoming magnetized is reluctance.

Supply the missing word or words in the following statement.

A material which is hard to magnetize is said to have a high __________.

//////////////////////

reluctance

Frame 20

A substance in which the molecules can change direction easily will be easy to magnetize. The term which refers to the ease with which a material can be magnetized is permeability.

Is the following statement TRUE or FALSE?

______ Because it is easily magnetized, soft iron has a high permeability.

//////////////////////

TRUE

Frame 21

The terms "permeability" and "reluctance" are opposites. A substance having a high permeability will have a low reluctance.

Fill in the word needed to complete the following statements.

1. A material that has a high retentivity will have a ______________ reluctance.

2. Because it has a high retentivity, you would expect alnico to have a high ______________.

3. Soft iron is easily magnetized but loses its magnetism almost immediately, therefore, soft iron has a ____________ permeability and a ______________ reluctance.

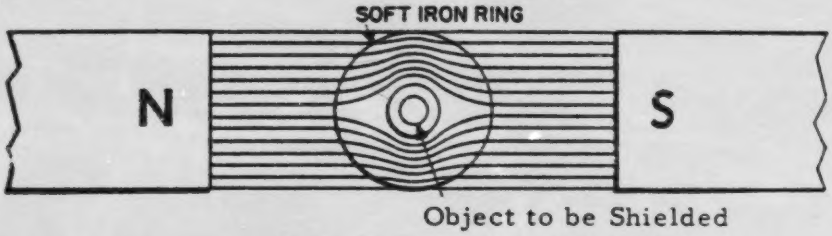
4. A material in which the molecules are highly resistant to a change in direction will have both high ______________ (be hard to magnetize) and high ______________ (tend to remain magnetized).

//////////////////////

1. high
2. reluctance
3. high
low
4. reluctance
retentivity

Frame 22

Magnetic lines of force can travel through all known substances; therefore, it is useless to try to block lines of force. In trying to protect instruments from magnetic effects, we follow the idea that if you can't stop lines of force, at least you can change their path. Lines of force can be deflected by a highly permeable material. When a permeable material is placed in a magnetic field, lines are drawn away from their regular path and flow through the permeable material rather than the space surrounding it.



//////////////////////

No Response Required

Frame 23

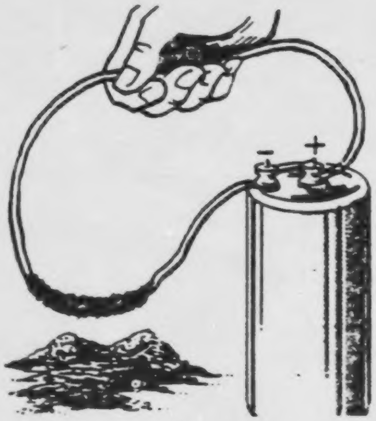
In the section of this package which you have just studied, we were concerned with the characteristics of magnets and their magnetic fields. Now let's try to tie-in what we've learned about magnetism with electricity.

//////////////////////

No Response Required

Frame 24

All conductors carrying current are surrounded by a magnetic field. If a wire (conductor) is connected to a battery and the wire is dipped into iron filings, these iron filings will be attracted and held by the wire. Study the illustration. This is proof of a magnetic field. If the circuit is opened by disconnecting one end of the wire from the battery, the filings will drop off. This is proof that the field exists only when current is flowing through the wire.



Fill in the word or words to complete the statement below.

Current flow in a conductor produces a ____________ ____________ which encircles the conductor.

//////////////////////

magnetic field

Frame 25

The lines of force take the form of concentric circles around the conductor. These magnetic circles are always going in one direction. Each line of force around the conductor acts like an elastic band. When current in the conductor increases, more lines of force are produced. Because they repel each other, some of the lines of force are stretched farther out from the conductor, but as soon as current flow decreases the lines spring back toward the conductor.

Mark the following statements TRUE or FALSE.

____a. When the current through a wire increases, the magnetic field around the wire becomes smaller.

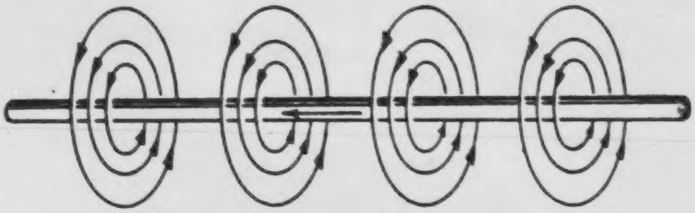
____b. Decreasing the current flowing through a wire will cause the number of magnetic lines of force around the wire to decrease.

//////////////////////

a. FALSE b. TRUE

Frame 26

The circular lines around the conductor in the illustration below represent the magnetic lines of force. They are shown this way to show that lines of force are present along the full length of the wire. Another characteristic of lines of force around a conductor, which you should keep in mind, is that the lines of force form at right angles to the direction of current flow.



//////////////////////

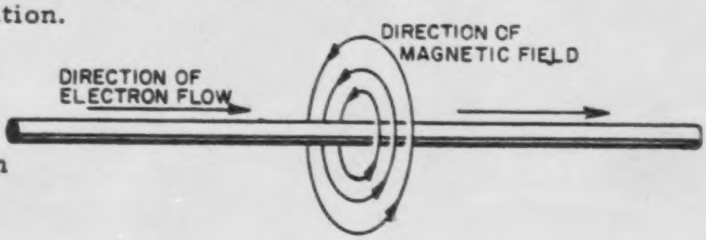
No Response Required

Frame 27

The magnetic field around a straight wire does not have a north or south pole. The lines of force are in circles rather than flowing from the north pole to the south pole. The direction in which current is flowing through a conductor determines the direction of the magnetic field around it. This relationship between direction of current and the magnetic field is shown in the accompanying illustration.

Complete the following statement.

The direction of the magnetic field is determined by the direction of the ____________ through the conductor.



//////////////////////

Current

Frame 28

The magnetic field around a conductor will collapse and then build back up again, but in the opposite direction when the current in the conductor is reversed.

Is the following statement TRUE or FALSE?

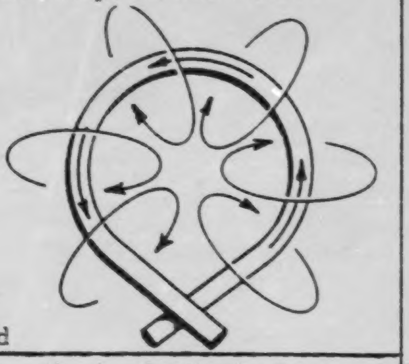
Reversing the current through a conductor will not reverse the direction of the magnetic field surrounding it. _______

//////////////////////

FALSE

Frame 29

If a conductor is bent into the form of a loop, all of the lines of force will continue to circle the conductor as before. The accompanying illustration shows that all the lines of force enter inside the loop, in the same direction. The fact that all lines of force point in the same direction inside a loop is important to understanding, because this is the principle of operation of coils and transformers. When a wire is bent into a loop, each line of force passes through the inside of the loop in the same direction, then circles around the outside of the loop to complete its path.

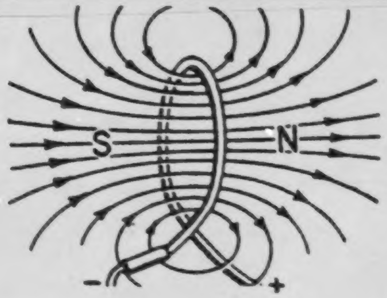


//////////////////////

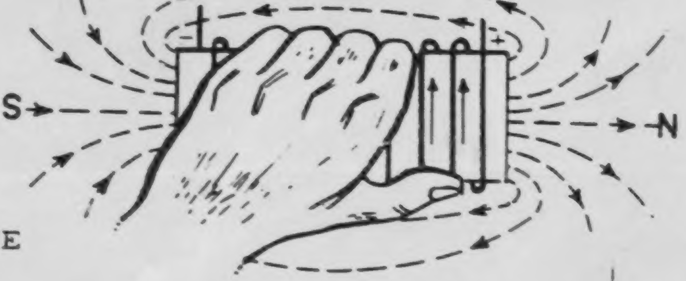
No Response Required

Frame 30

A loop of wire has poles just like a bar magnet. All lines of force enter on one side of the loop and leave from the other side of the loop. Thus, a north pole is created on one side of the loop and a south pole on the other. Study the illustration and see if you can determine why this is so.



The left hand rule is used to determine the polarity of a loop (coil). If you grasp the coil (loop) with the left hand so that your fingers point in the direction of current flow, your thumb points toward the north pole.



Is the following statement TRUE or FALSE?

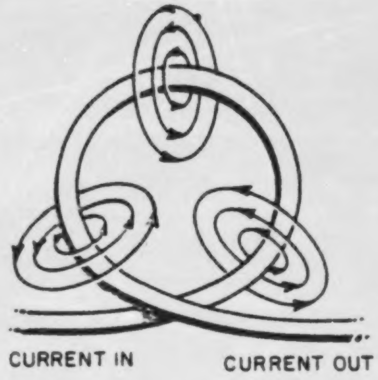
The magnetic field around a loop of wire sets up a north and a south pole.

//////////////////////

TRUE

Frame 31

When a straight wire conductor is bent into a loop, the same number of lines of force still surround it. The lines of force, however, are more concentrated inside the loop. In the illustration you see that bending the wire brings the lines of force inside the loop closer together.



From the choices listed in the left column below, select the correct one to be inserted in the blank space in the statement in the right column.

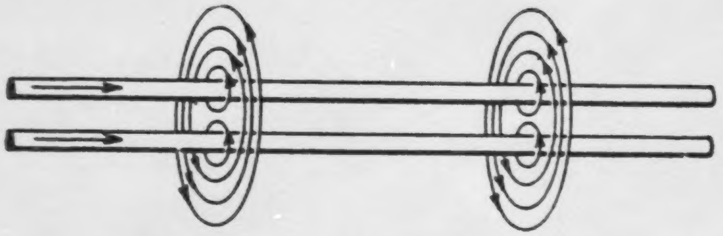
a. weaker	1. If the lines of force are pushed closer together inside a loop of wire, the flux density of the magnetic field will be ____________ inside the loop than outside.
b. greater	
c. opposite	
d. less	

//////////////////////

b. greater

Frame 32

If two current-carrying conductors are placed side by side (parallel to each other), in the area between the two wires the fields oppose each other and the lines of force tend to circle both wires. When the magnetic fields of the wires combine in this way, the combined field is greater than the field around either of the separate wires. Study the illustration and notice that the magnetic field of the two wires combine only if the currents in them are flowing in the same direction.



Circle the letter for the correct answer to the statement below.

The magnetic fields of two wires will combine if the currents in them are flowing.

- a. in opposite directions
- b. from north to south
- c. in the same direction
- d. from south to north

//////////////////////

c

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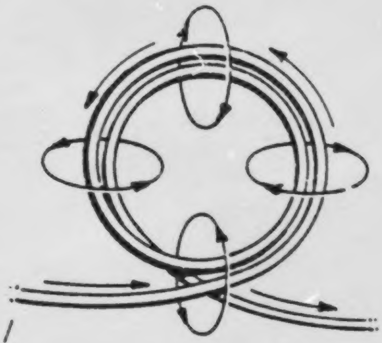
Frame 33

When a wire is bent into two loops that are spaced near each other, the magnetic fields around the two loops will combine. Study the accompanying illustration and notice that the current is flowing in the same direction through each loop, and that the magnetic fields of each loop combine, forming a larger magnetic field. When a conductor is wound into a coil of many loops or turns, the magnetic fields around all the loops of wire tend to combine to form a much larger magnetic field.



Mark the following statements TRUE or FALSE.

1. If a wire is wound into a two-coil loop, the fields of the two loops will combine. _____

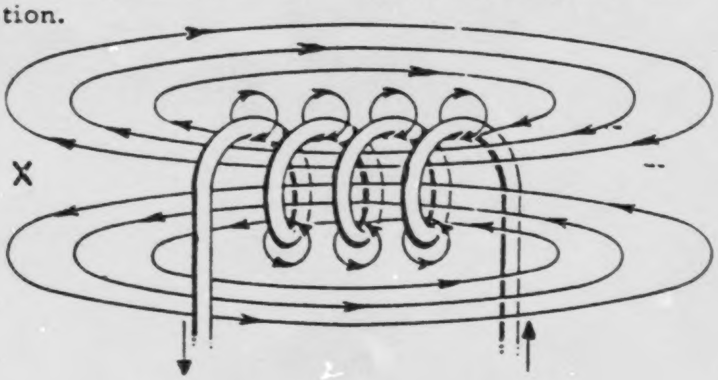
2. When a conductor is wound into a coil, the coil has all the properties of a magnet. _____

/////////////////////

1. TRUE 2. TRUE

Frame 34

All lines of force inside a coil point in the same direction. In a bar magnet the lines of force inside the magnet travel from the south pole to the north pole. The direction of the lines of force inside a coil is the same as in a magnet. Study the illustration very carefully and then answer the following question.



Complete the following statement.

The pole of the coil labeled X is the _____________ pole of the coil.

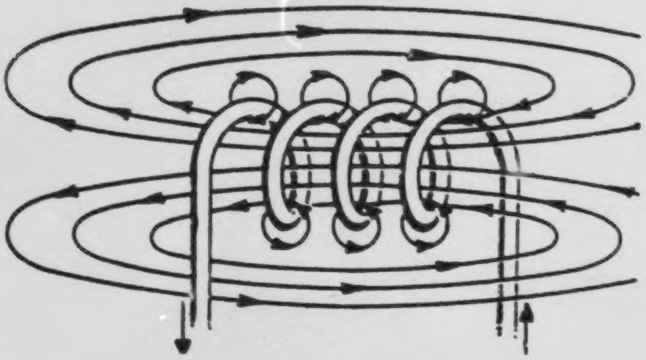
/////////////////////

north

162

Frame 35

Study the illustration below and notice that the magnetic field of the coil has one direction inside the coil and the opposite direction outside the coil.



Using the illustration above answer the following questions by filling in the required information.

1. The north pole is the (left/right) end of the coil. ______________

2. The external lines of force leave the coil at the __________ pole and return to the coil at the ________ pole.

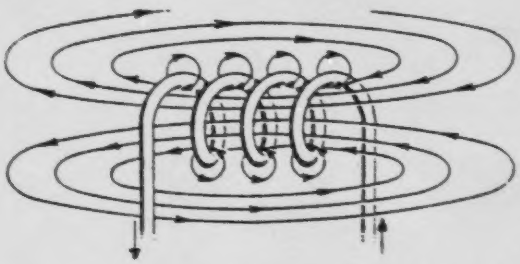
//////////////////////

1. left   2. north south

Frame 36

The direction of current through the loops of a coil will determine which end of the coil is a north pole and which end is the south pole. If the direction of current is reversed, the polarity of the coil will also be reversed.

In this illustration current flow is in the direction of the arrow shown at the ends of the conductor. From the information given in the diagram, answer the following question.



If the end of the coil which is a north pole becomes a south pole, this means that current through the coil has ________________.

///////////////////////

reversed

Frame 37

Because the direction of polarity in a coil depends on the direction of current flow through the coil, we know it is possible to determine which end of the coil is a north pole if the direction of current flow is known. This is made possible by using the left-hand rule as it was explained in Frame 30.

Recall the use of the left-hand rule and complete the following statements by selecting the correct answers.

1. In using the left hand rule, the fingers circle the coil in the direction of
   - a. current flow.
   - b. the magnetic field.
   - c. the north pole of the coil.
   - d. the south pole of the coil.
2. In using the left-hand rule, the thumb points in the direction of
   - a. current flow.
   - b. the magnetic field.
   - c. the north pole of the coil.
   - d. the south pole of the coil.

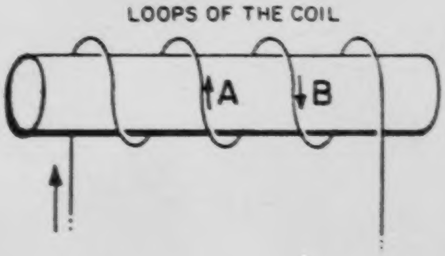
//////////////////////

1. a 2. c

Frame 38

In order to use the left-hand rule to determine the north pole of a coil, you must first determine the direction of current flow through the loops of the coil. If you know from which direction current enters the coil, you can trace it through the loops of the coil.

Trace through the coil in the illustration, starting where current enters the coil.



Is current flowing in the direction of arrow A or arrow B?

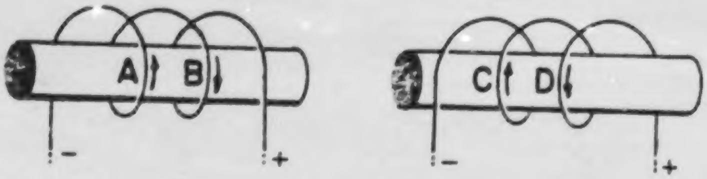
//////////////////////

Arrow B

Frame 39

If a coil is connected to a battery, current will flow from the negative (-) terminal of the battery, through the coil, and back to the battery at the positive (+) terminal. Sometimes it is more convenient not to show the battery connected to the coil. The direction of current flow can still be shown by a minus (-) sign near one lead of the coil and a plus (+) sign near the other.

Study the following illustrations and answer the question by selecting the letter from the correct answer.



The direction of current through these coils is correctly indicated by arrows

a. A and C.
b. B and D.
c. A and D.
d. B and C.

//////////////////////

d. B and C.

Frame 40

In the following statement, supply the missing word which will complete the statement.

The rule, "If you grasp a coil so that your fingers point in the direction of current flow, your thumb will indicate the direction of the north pole of the coil," will work only if you use your ____________ hand.

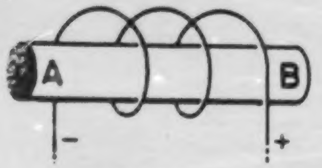
////////////////////

left

Frame 41

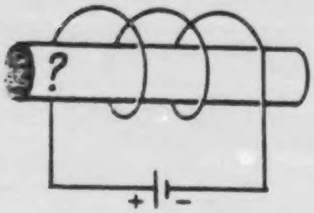
Now, see if you can tell which end is the north pole of the coil in these illustrations.

1.



a. A
b. B

2.



In the illustration above, the pole with the question mark (?) is a ____________ pole.

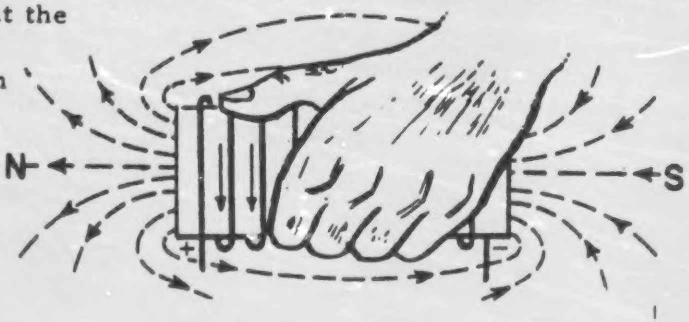
////////////////////////

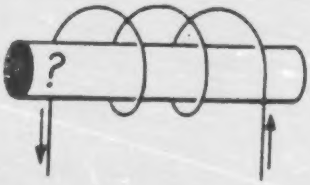
1. a 2. south

NOTE: If you missed either of these questions (Frame 41), read Frame 42 carefully. If you answered Frame 41 correctly, proceed directly to Frame 43.

Frame 42

If you are reading this, it is because you are still unable to determine polarity and you missed the problems asked in Frame 41. We'd better review. If your left hand is placed so that the fingers point in the direction of current around the coil as shown in the illustration, your thumb will then point in the direction of the north pole. Now remember this rule. Let's see why you missed the problems in Frame 41. Problem number 1 can be solved by using the left-hand rule as stated above. In problem number 2, you say the north pole is not the one in question? You are absolutely correct. The question mark (?) is on the pole opposite the north pole. This being the case, take another look at the diagram. The pole in question, therefore, is the ____________ pole of the coil.





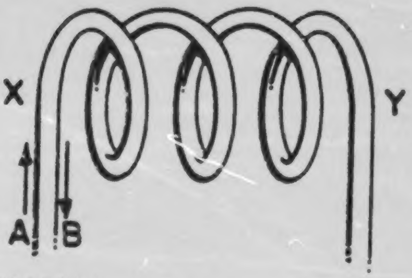
////////////////////////

south

Frame 43

Study the accompanying diagram and supply the information in the blank space.

If the current through the coil in the diagram is flowing in the direction of arrow A, the pole labeled __________ will be the north pole of the coil.



////////////////////////

pole x

Frame 44

By using the left-hand rule, polarity can be determined if the direction of the current flow is known. You may also be required to determine the direction of current entering a coil when the polarity is known. This can be done by using the same left-hand rule and simply reversing some of the steps learned here. But you ask "How can I know which is the north pole of the coil if I don't know the direction of current flow?" The polarity of a coil can be determined by using a compass. If the compass needle is placed near a pole of a coil, and the south needle of the compass points toward the coil, you should be able to figure out that this pole of the coil, to which the south compass needle points, must be a north pole. Remember, unlike magnetic poles attract.

//////////////////////

No Response Required

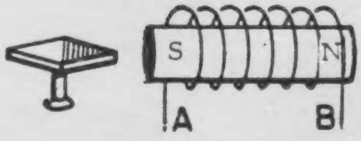
Frame 45

Be sure that you have these steps firmly in mind:

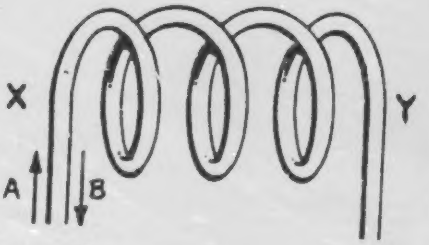
1. Determine which end of the coil is the north pole.
2. Place your left hand around the coil in such a way that your thumb points toward the north pole.
3. In this position, your fingers will point in the direction of current.
4. Follow along the wire of the coil, to determine where current enters and leaves the coil.

Study the diagrams which follow and then answer the questions by filling in the required information.

1. A is the _______ (+ or -) lead of the coil.



2. If X is the south pole of the coil shown below, then the current through it must be flowing in the direction of arrow ________.



////////////////////////

1. + 2. B

Frame 46

There are several factors which affect the magnetic strength of a coil. One of these is the amount of current flowing through the coil. When current flow increases, the magnetic strength of the coil increases.

Is the following statement TRUE or FALSE?

If you wished to change the magnetic strength of a coil, one way in which this could be done would be to increase the current flow in the coil. _____

////////////////////////

TRUE

Frame 47

Another factor which affects the magnetic strength of a coil is the number of turns in the coil. The magnetic strength also depends upon how close the turns in the coil are to each other. When the turns are relatively far apart, many of the lines of force will circle one turn of the coil only. When the turns are close together, a great many more lines of force will encircle the entire coil.

Remembering what you have just read, complete the following statements.

1. A coil with five turns will have greater _________ strength than a coil with two turns.

2. The magnetic strength of a coil may be increased either by increasing the _________ flow through the coil or by increasing the number of ___________ per inch in the coil.

/////////////////////

1. magnetic 2. current, turns

Frame 48

If a soft iron bar is inserted into a coil, the magnetic strength of that coil will be increased tremendously. The reason for this is that the iron is much more permeable than air, therefore more lines of force will flow through the iron.

Is the following statement TRUE or FALSE?

Another way of increasing the magnetic strength of a coil is by inserting an iron bar into the coil. ______

/////////////////////

TRUE

Frame 49

A current-carrying coil which has an iron core is called an electromagnet. Some electromagnets are so large and powerful that they can lift tons of scrap metal at one time. Other electromagnets used in some electrical and electronic circuits are very small. All of them are made up of coils of current-carrying wire and a core of magnetic material.

The coils used in electromagnets are often called solenoids. Many electrical devices use solenoid coil electromagnets. If a circuit breaker is connected to electrical wiring so that the current must flow through the contacts and the coil, it can be used to protect a circuit from electrical overloads.

Fill in the word or words to complete the following statement.

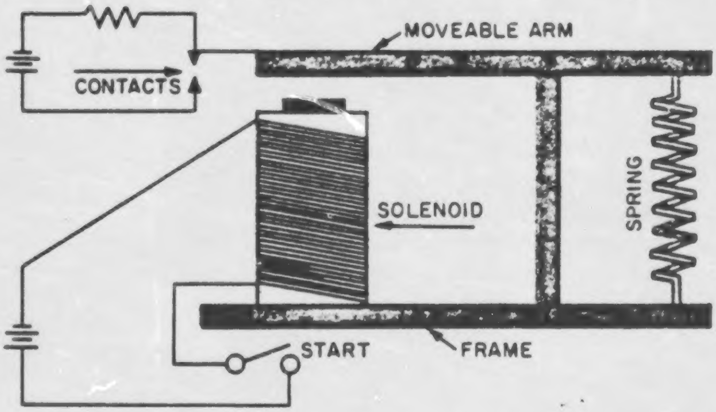
A current-carrying coil which has an iron core is called an __________.

////////////////////////

electromagnet

Frame 50

Another electrical device in which electromagnets are used is the relay. A relay makes it possible to control a circuit from a remote point. In working with equipment, you will find relays used quite frequently. You will also find that some relays are much more complicated than others, but the principle of their operation will be the same. In the relay circuit shown here, closing the switch labeled START allows current to flow through the solenoid causing it to become a magnet. The movable arm is then drawn toward the magnet so that the contacts are brought together, thus completing or closing the circuit. When the starting switch is opened, current stops and the solenoid is no longer a magnet. The contacts then open because of the action of the spring.



Is this statement TRUE or FALSE?

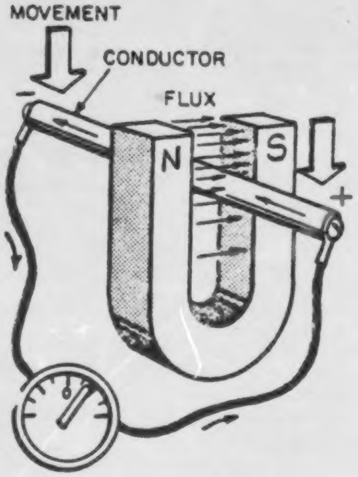
If for safety or convenience it is desirable to energize a circuit from a distance, this can be done by using a device called a relay. _____

///////////////////////

TRUE

Frame 51

In the preceding frames, you saw how a magnetic field is produced by an electrical current. This is only one part of the connection between electricity and magnetism. Another part of this connection is producing an electric current by a magnetic field. We already know that current flowing through a wire always produces a magnetic field around the wire. Under certain conditions, a magnetic field can produce current flow in a wire. However, it is more acceptable to say that a magnetic field can produce an emf (electromotive force) and this emf can cause current flow when there is a complete circuit. The accompanying illustration demonstrates this fact.



Supply the missing information in the following statement.

If a conductor is moved through a magnetic field, an emf (electromotive force) is generated in the conductor causing ________________ to flow in the circuit.

////////////////////

current

Frame 52

If the conductor is held stationary and the magnet moves, current flow is produced. Current flows only when the conductor is cutting lines of force in a magnetic field. In order to cut lines of force, motion is necessary, and this motion can be caused by moving either the magnet or the conductor.

The faster a conductor moves through a magnetic field, the more lines of force it will cut in a given period of time. This, of course, will result in a greater emf being induced into the conductor.

Is the following statement TRUE or FALSE?

Increasing the speed of movement through a magnetic field will decrease the amount of emf induced. _____

///////////////////////

FALSE

Frame 53

The stronger the magnetic field a conductor moves through, the more lines of force the conductor will cut, causing more emf or voltage to be induced. So, to increase the amount of emf induced, it is necessary to either move the conductor or magnet faster or increase the flux density of the magnetic field.

This process of producing an emf from movement of a conductor with relation to the magnetic field is called electromagnetic induction.

Complete the following statement.

Generating an emf in a conductor by a magnetic force is called

_________________ _________________.

//////////////////////

electromagnetic induction

Frame 54

Three things are necessary for electromagnetic induction to take place: (1) a conductor, (2) a magnetic field, and (3) motion - (movement between the magnetic field and the conductor so that lines of force are cut by the conductor).

Answer the following question YES or NO.

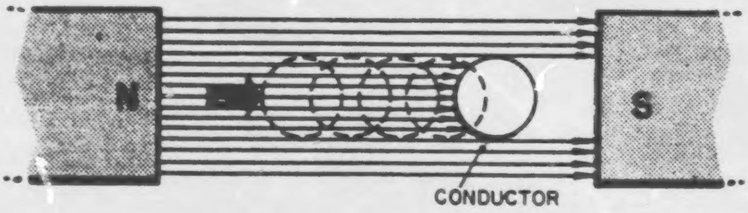
Will an emf be induced if a conductor is within a magnetic field, but is not moving with respect to the magnetic field? _________

//////////////////////

NO

Frame 55

In the illustration below, the conductor in the magnetic field is moving parallel to the lines of force. Is there an emf being induced? Why?

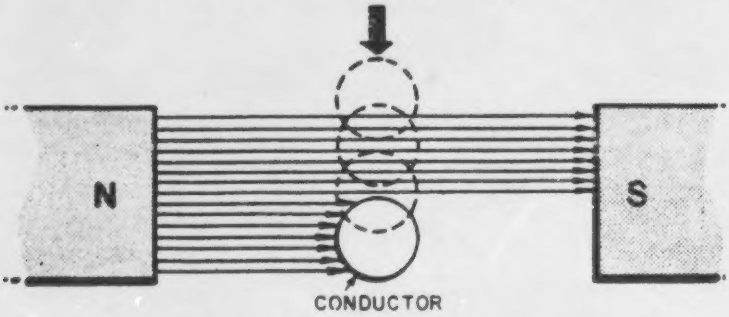


//////////////////////

No. The lines of force are not being cut by the movement of the conductor.

Frame 56

If the conductor, in the illustration below, moves through the magnetic field in the direction indicated by the arrow, will an emf be generated?



//////////////////////

YES

Frame 57

The three things necessary in order for electromagnetic induction to take place are: a ________________, a ____________ ______________, and ________________.

//////////////////////

conductor, magnetic field, motion

Frame 58

At the present time, electromagnetic induction is the most practical method of producing a large amount of electrical power, since it uses readily available mechanical energy to produce this power. By using a magnetic field, it is possible to produce electrical power from mechanical energy. We could say that electromagnetic induction is the process for converting mechanical energy into electrical energy. A generator is actually a machine which produces electrical power by the process of electromagnetic induction. Some mechanical force or energy is always necessary in electromagnetic induction in order to move the conductor through the magnetic field.

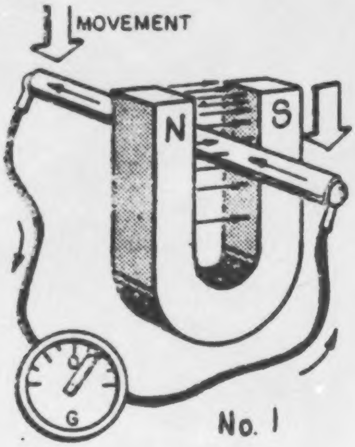
We know that when a conductor is moved through a magnetic field an emf is induced which in turn causes ____________ to flow in the conductor.

//////////////////////

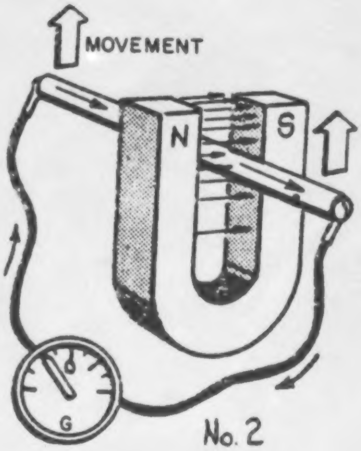
current

Frame 59

The resulting current flow in a conductor, caused by the conductor cutting the lines of force, flows in one direction or the other according to the direction that the conductor moves through the magnetic field. Compare the two illustrations below and notice that current flow in illustration 1 is opposite in direction to current flow in illustration 2.



No. 1



No. 2

If the direction in which the conductor is moved through the magnetic field is reversed, the direction of the induced current will be _______________.

/////////////////////

reversed

Frame 60

These statements which have been made in the last few frames may have, we hope, struck a note of familiarity. Do you recall the terms directed current (dc) and alternating current (ac)? If this induced current is caused to flow in the same direction at all times, this would be direct current (dc). If the direction of induced current is caused to change its direction, alternating current (ac) would be produced.

Notice that not only does the direction in which the conductor is moved through the magnetic field determine the direction of the induced current, but also the direction of the magnetic field. If either of the two are reversed, the current will be reversed.

Fill in the missing word or words in the following statement.

Direction of the induced current depends upon the direction of the movement of the conductor through the magnetic field and the direction of the

_______________ _______________.

/////////////////////

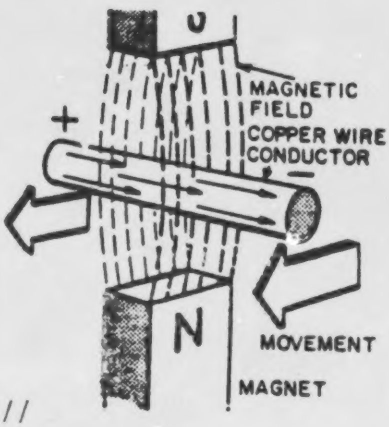
magnetic field

Frame 61

Take a look at the illustration. If the polarity of the magnet changes so that the North Pole becomes a South Pole and the South Pole becomes a North Pole, providing the conductor moves in the same direction as before, the induced current will

a. still flow in the same direction.

b. flow in the opposite direction.



//////////////////////

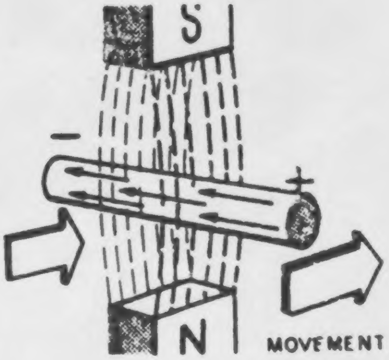
b

Frame 62

In this illustration, if the direction of movement of the conductor is reversed, the direction of the current flow in the conductor will

a. reverse.

b. not change.



//////////////////////

a

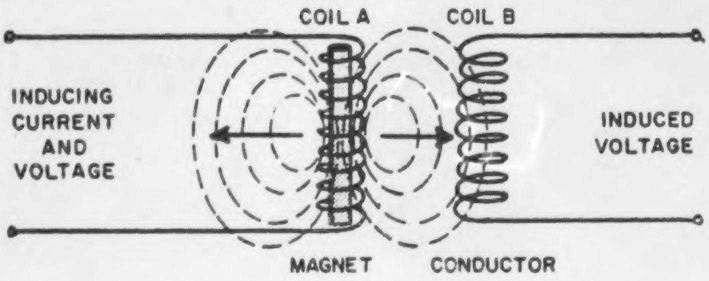
Frame 63

In Frame 62 we showed how this induced current in the conductor can be made to flow in one direction (dc) or be made to flow first in one direction. reverse itself, and then flow in the opposite direction (ac). Since ac is to be covered at a later time, we would like to expand just a little more on this subject and show that there is a situation in which both the magnet and the conductor can remain stationary, yet an emf can be induced. This will happen if an electromagnet, in which the current is continually reversing directions, is supplying the inducing force. Proceed to the next frame and let's see how this happens.

//////////////////////

No Response Required

Frame 64



In the following illustration, we show two coils. One coil has a soft iron core, with current flow through the one labeled Coil A. As the current through Coil A is increasing, the lines of force around it will be expanding. As these lines of force expand, some will cut through Coil B, creating motion between the magnetic field and Coil B. (This is because the magnetic field is moving with respect to Coil B.) Some lines of force will cut across the conductors and a voltage will be induced in Coil B.

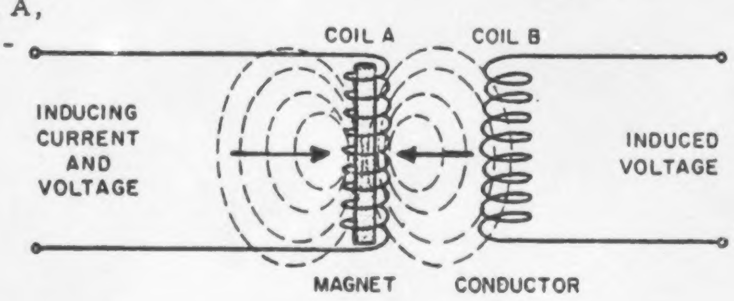
Refer to the illustration above and complete this statement.

With the magnetic field cutting across the second coil, a voltage will be induced in Coil ____________.

//////////////////////

B

Frame 65



If the current through Coil A, in the following diagram, is decreasing, the lines of force around it will be decreasing. Again, some of the lines of force will be moving through Coil B, creating a motion between the magnetic field and Coil B. In collapsing, some of these lines of force cut across Coil B inducing a voltage, but in an opposite direction from the situation in Frame 64 (notice the arrows drawn in the magnetic field).

It is logical, therefore, that when the current in Coil A is steady (neither increasing nor decreasing) there will be no current flowing in Coil B.

Complete the following statement by supplying the word or words necessary to do so.

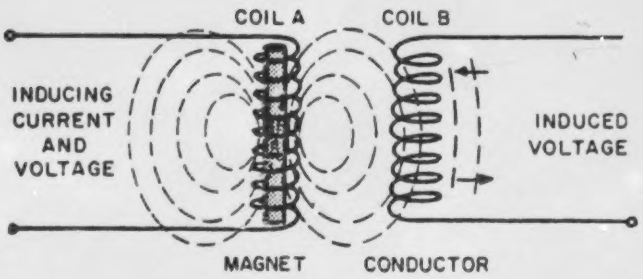
Since the lines of force that are cutting the conductor are moving in the opposite direction from when the field was expanding, the current induced in Coil B will be ____________________.

//////////////////////

reversed

Frame 66

If the current in Coil A, in the illustration is continually reversing directions, as indicated by the arrows, its magnetic field will be continually expanding and collapsing so that lines of force will be cutting back and forth across Coil B, causing the induced current in Coil B to continuously change directions.



Study the illustration and complete the following statement.

An emf can be induced even though the magnet and the conductor do not move, if the ________________ in the coil is continually changing directions (alternating).

//////////////////////

current

Frame 67

In conclusion, there is one last statement concerning transformers which is exactly what we have been using in our illustrations. The amount of induced voltage in the second coil, referred to as the secondary winding, can be made greater or smaller than the voltage (or current) used to create the induced voltage (or current). This is done by having more or less windings in one coil than in the other. This is where the terms step-up or step-down transformers are applied to the transformer itself. A transformer is an electrical device which transfers electrical power from one circuit to another by mutual inductance.

//////////////////////

No Response Required

Frame 68

In the previous part of this package you learned the basic terminology and fundamentals of producing electricity. In this part you will learn the definition of current, voltage, and resistance. Also you will learn the effect of current flow and the symbol for current; how the type of material, length and size of the conductor affects current flow. You will learn what voltage is, its symbol, and methods of producing voltage. Then, too, you will learn about resistance, as applied to electricity, and its symbol, and ways of measuring resistance.

//////////////////////

No Response Required

Frame 69

To provide you with an understanding of current flow, we can compare it to the flow of water, and the drops of water to electrons. Just where do these electrons come from?

To answer this question, it will be necessary to recall the term MATTER. You remember that matter is anything that occupies space and has weight. Everything around us is ________________.

//////////////////////

matter

Frame 70

We can further say that all matter is composed of elements, which are materials in a pure form; or compounds, which are combinations of elements. Every element is composed of electrons, protons, and neutrons. The atoms of the different elements differ only in the number of electrons, protons, and neutrons they possess. Of course, there is more to the atom than has been mentioned here, but we are mainly concerned with the electron because of current flow.

Copper is a pure metal, and therefore is an ________________, while brass, composed of several elements, is a __________________.

//////////////////////

element compound

Frame 71

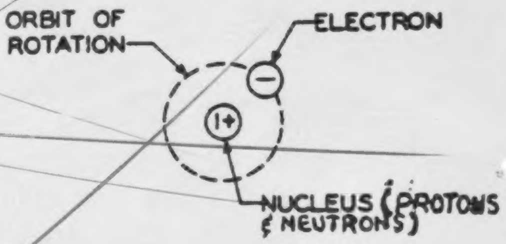
If we could take copper, for instance, and break it down into smaller and smaller pieces, eventually we would have an invisible particle which is called the atom.

An atom is the smallest particle into which an ________________ may be divided and still retain the characteristics of the original element.

//////////////////////

element

Frame 72



HYDROGEN ATOM

The internal structure of the atom is similar to that of our solar system. The electrons traveling in orbits around the nucleus, or center of the atom, are similar to the planets in our solar system.

In the illustration, the parts of the atom which travel in paths about the centers of the atom are called

________________.

//////////////////////

electrons

Frame 73

The center of the atom or nucleus is made up of protons and neutrons.

While electrons travel in orbits or paths around the nucleus, ____________ and ____________________ are located inside the nucleus.

//////////////////////

protons neutrons

Frame 74

Electrons and protons are important because they have electrical charges. There are two types of electrical charges: negative and positive.

The electron carries a negative electrical charge and the proton carries a positive electrical charge. The neutron is the part of the atom which has no electrical charge.

1. Electrons carry ______________ electrical charges while ____________ carry positive electrical charges.

Are the following statements TRUE or FALSE?

___ 2. A neutron is a neutral particle.

___ 3. A positively charged body has more electrons than protons.

//////////////////////

1. negative protons	2. TRUE	3. FALSE

Frame 75

Since the protons (positive charges) remain in the nucleus of the atom, the charge of the atom is determined by the number of electrons.

An atom with more electrons than protons is ____________ ____________

//////////////////////

negatively charged

Frame 76

One of the basic laws of science is the law of attraction and repulsion, which tells us how electrically charged particles react to each other.

Are the following statements TRUE or FALSE?

___1. The law states that like charges attract and unlike charges repel.

___2. Since electrons carry like charges, the force existing between two electrons is one of repulsion.

___3. A proton and an electron have unlike charges and the force existing between the two is one of attraction.

//////////////////////

1. FALSE 2. TRUE 3. TRUE

Frame 77

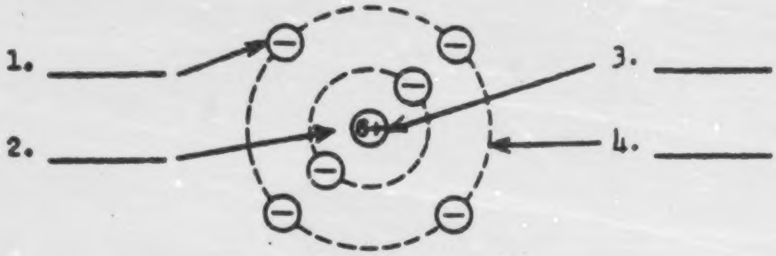
In the next series of frames, we will discuss how current flow takes place in a conductor (wire).

Let's say that the movement of drops of water through a pipe is the same as the movement of electrons through a wire, or in other words, current flow.

For the time being, we'll say that a piece of wire is made up of atoms which contain one electron and one proton. In diagramming the particles of an atom, we use a small circle with either a plus(+) or minus (-) symbol inside to represent protons or electrons. Since electrons carry a negative charge the minus (-) symbol inside the circle represents these particles and, of course, the protons are represented by a plus (+) symbol inside the circle, since they carry a positive charge.

Using the illustration below, match the numbered blanks with the appropriate letters for the particles listed below.

a. Neutron
b. Electron
c. Orbit path
d. Proton
e. Nucleus



CARBON ATOM

//////////////////////

1. b 2. e 3. d 4. c

Frame 78

1. We know that a force of repulsion exists between ________________ (like/unlike) charges; therefore, between + and + (two protons) there exists a force of ____________________ (attraction/repulsion).

2. We also know that a force of attraction exists between ____________ (like/unlike) charges; therefore, between - and + (one electron and one proton) there exists a force of ________________ (attraction/repulsion).

//////////////////////

1. like repulsion 2. unlike attraction

Frame 79

In the next few frames, let's see how electrons are injected into the wire by a source of voltage.

As we have said earlier, it is the movement of these negatively charged electrons that perform work, such as lighting lights, turning motors, etc. Before we can determine the amount of current in a circuit, we must have some unit to measure it by. This unit of measurement of current is the ampere. An instrument called an "ammeter," which you will study later, is connected into the circuit to measure or count the number of amperes of current.

In any circuit, the value read on the ammeter scale indicates the number of ______________ of current flowing through the circuit.

//////////////////////

amperes

Frame 80

Most electrical terms are abbreviated. Two such abbreviations for the ampere are amp or a. Sometimes these abbreviations appear as capitals, however, in either case the meaning is the same.

The amount of current flowing through a wire, in some cases, may be unknown. To indicate that there is current flow in the wire, the capital letter I is used. This is the symbol used for current "INTENSITY" (intensity means how much is flowing).

Supply the missing word or words to the statements below.

1. We know that the ____________ is the unit of measurement for current.
2. The letter I and ampere ____________ (do/do not) mean the same.

//////////////////////

1. ampere 2. do not

Frame 81

So far, in this package, the term "voltage" has been used but not properly explained. Voltage is the most widely used term to describe electrical pressure, or the force which causes the electrons to move through a conductor. Another term which means the same thing is electromotive force (emf or EMF).

Supply the missing word or words to the statements below.

1. We learned that the letter I is the symbol for ______________; the symbol used for voltage is E, which was probably taken from the term ____________ ____________.

2. The force that causes electron movement is __________ or __________ ________________.

//////////////////////

1. current electromotive force 2. voltage electromotive force

Frame 82

To cause current flow in a circuit, a force (voltage) must be applied. This voltage or emf is expressed in volts, and is measured by a voltmeter.

The ______________ is the unit of measurement for voltage for which the abbreviation is V.

//////////////////////

volt

Frame 83

There are various ways by which voltage can be produced. In the first part of this package, we learned that when a wire is moved through the invisible lines of force which surround a magnet, a current is induced into the wire. Generators use this principle of electromagnetic induction to produce useful amounts of voltage. Another method of producing useful amounts of voltage is by batteries, which use checmical reaction to produce voltage.

Chemical reaction (battery) and magnetic induction (generator) are two methods of producing useful amounts of ______________.

//////////////////////

voltage

Frame 84

At the beginning of this section dealing with current, we said that along with learning about current and voltage, you would also learn how the type of material, length and size of the conductor affect current flow. These factors are useful in controlling the amount of current and their effect on current flow is stated in terms of resistance.

Resistance is a property all materials have in varying amounts which tends to oppose or resist the flow of current and is similar to friction in mechanics. A force must be applied to overcome friction. For example, if we tried to push a stalled car, we would exert a force on the car through the physical act of pushing. However, friction in the car opposes our efforts to move the car. This same idea is true of the resistance to current flow in electrical circuits, and voltage is the force which overcomes this opposition.

Supply the missing word or words to the statements below.

1. In electrical circuits, opposition to the flow of current is called ______________. The force which overcomes this opposition or resistance is called ______________.

2. To cause current to flow through a material which resists or opposes the flow of current, a source of ______________ is necessary.

//////////////////////

1. resistance voltage 2. voltage

Frame 85

The three quantities, current, voltage, and resistance are interrelated:

Supply the missing word or words to the statements below.

a. The force which causes current to flow is ______________.

b. The movement of electrons is ______________.

c. The opposition to electron flow is ______________.

////////////////////////

a. voltage b. current c. resistance

Frame 86

The unit of measurement for resistance is the ohm. The Greek letter omega (Ω) is the abbreviation for ohms. However, the amount of resistance a material offers to current flow is expressed as so many ohms (Ω), rather than so many omegas. Resistance is represented by using the capital letter R.

Write the missing words in the appropriate spaces below.

1. The ohm is used to measure the ______________ a material offers to current flow.

2. The symbol Ω is the abbreviation for __________.

3. From earlier frames in this lesson, we know that I represents ______________, and E represents ______________.

4. The ___________ is the unit of measure for opposition.

5. The ___________ is the unit of measure for current flow.

6. The ___________ is the unit of measure for electrical force.

7. The letters V, a, and Ω are the abbreviations for ______________, ______________, and ______________.

8. Resistance is represented by the letter _________, but is measured in ______________.

/////////////////////

1. Resistance or opposition 2. Ohm 3. Current/voltage
4. Ohm 5. Amp or ampere 6. Volt
7. Voltage/ampere/ohm 8. R ohms

Frame 87

We know from earlier statements that elements differ only in the number of electrons. An atom of an element which has more electrons than an atom of an element with less electrons would be the better conductor. Consequently, current would flow more easily in this conductor.

Supply the missing words to the statement below.

As a result of this statement, we can say that the type of material of which the conductor is made affects ______________ ______________.

/////////////////////

current flow

Frame 88

We have explained the symbols and measurement terms for current, voltage, and resistance in the preceding part of this package. It is possible to compute the values of current, voltage, and resistance in any circuit by using Ohm's Law. This principle or law can be expressed as a formula. Keep in mind the symbols for current, voltage, and resistance and use them when applying Ohm's Law.

From the answers below select the column which has the correct symbols for current, voltage, and resistance by placing a check (✓) in the appropriate box.

☐ a. C	☐ b. I	☐ c. C	☐ d. I
V	V	E	E
R	R	R	R

//////////////////////

d

Frame 89

Ohm's Law deals with the relationship which exists between current, voltage, and resistance in an electrical circuit. By applying Ohm's Law to an electrical circuit we can determine the amount of current, voltage, and resistance in the circuit as a whole or in any part of the circuit.

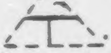
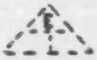
In this part of the package you will be introduced to Ohm's Law and shown how it can be used in solving simple problems and also how, with the aid of Ohm's Law, a change in one quantity (I, E, or R) will affect the others

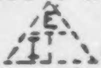
//////////////////////

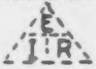
No Response Required

Frame 90

Ohm's Law states that the current (I) in a simple circuit is equal to the voltage (E) applied to the circuit divided by the resistance (R) of the circuit. This statement, written as a formula is: $I = \frac{E}{R}$

There is a method by which the formula for Ohm's Law can be more easily remembered. We might call this a memory device. Let's draw a triangle; and then let's place a "T" inside it; . Now let's place the symbols for the three quantities (I, E & R) in these parts of the triangle. E will always be placed in the upper portion of the triangle above the T; 

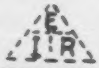
; I is placed in the lower left-hand section of the triangle; 

, and R is placed in the lower right-hand section; 

. From the information given in the previous statements, draw the memory device in the space provided as it was explained and then place the symbols in their appropriate locations.

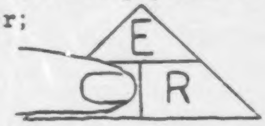
a. ____________________

//////////////////////

a. 

Frame 91

The Ohm's Law memory device is easy to use. Suppose, for example, you need to determine the current in a particular circuit and you know the value of the voltage being applied, and you also know the resistance value. Since current is the one value which you don't know, simply cover the I in the lower left part of the triangle with your finger; Now, the two remaining quantities, E and R are still exposed, with E above R. We know that when a value is shown above another value, this merely means to divide the one on top by the one on the bottom. So E divided by R equals I, which is the quantity we are solving for.



In the space below, draw the memory device and use it to write the formulas for finding E, I, and R.

E = ______________.

I = ______________.

R = ______________.

//////////////////////

$E = I \times R \qquad I = \frac{E}{R} \qquad R = \frac{E}{I}$

Frame 92

Now we have a tool which will help us to determine the method for calculating for an unknown value. Any time that two values in any circuit are known, we can solve for the third by applying Ohm's Law in one form or another.

Place a check (✓) beside the true statement.

____a. The memory device can be used any time one of the values is known.

____b. To use the memory device, two of the values must be known.

____c. The symbol I is always placed in the top of the triangle.

____d. The symbol E is used to represent current.

/////////////////////

b

Frame 93

$I = \frac{E}{R}$ is only one application of Ohm's Law. By substituting values for voltage (E) and resistance (R), you can calculate the currents (I). Or by substituting values for current and resistance, you can calculate the voltage, just as substituting voltage and current values, helps to calculate the resistance.

For example, let's say that with 24 volts applied in a circuit which offers 6 Ω of resistance, what is the current flow in the circuit? Using the formula $I = \frac{E}{R}$ and substituting the known values, we can determine the current flow. We know that E = 24 volts and R = 6 Ω. So $I = \frac{24 \text{ volts}}{6\,\Omega}$. Dividing 24 volts by 6 Ω, we find that I = 4a.

Let's try another one. If 12 volts is being applied to a circuit with 6a of current, what is the resistance? Use the above rule for applying Ohm's Law and calculate on a sheet of scratch paper the amount of resistance in the circuit. Which of the answers below is correct?

a. 2 Ω
b. 4 Ω
c. 6 Ω
d. 72 Ω

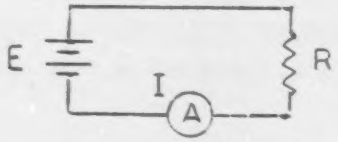
//////////////////////

a

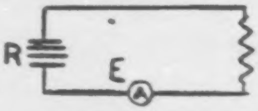
Frame 94

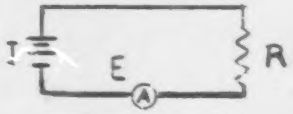
In an earlier frame we mentioned a simple circuit and the application of Ohm's Law to this type of circuit. As we will find out later, the characteristics of current, voltage, and resistance are a little different in different types of circuits. In either case we represent circuits schematically as illustrated below, and the quantities are represented by their symbols.

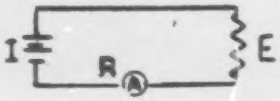
Study the illustration and learn to use this method of diagramming a circuit. You will notice that in our illustration of a circuit we have used the symbol A for an ammeter, as if we were actually measuring the amount of current (I) flowing in the circuit.

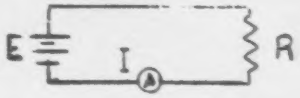


Just to be able to recognize electrical circuits when they are constructed by the use of schematic drawings, in the spaces below, place a check (✓) beside each drawing which you believe to be diagrammed correctly.

______a.


______b.


______c.


______d.


//////////////////////

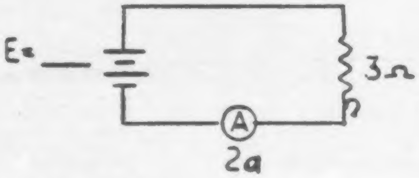
d

Frame 95

Now let's try to solve for a missing quantity and apply Ohm's Law in calculating for this missing value.

Given:
I = 2 amperes (a)
R = 3 ohms (Ω)

Find:
E = ___________



///////////////////////

6v (E = I x R)

Frame 96

Remember from one of the beginning frames, we said that in this part of the package you would be shown how a change in one quantity (E, I, or R) will affect the others. For the next few frames let's see if this is true. What effect will a change in voltage have on current? On resistance?

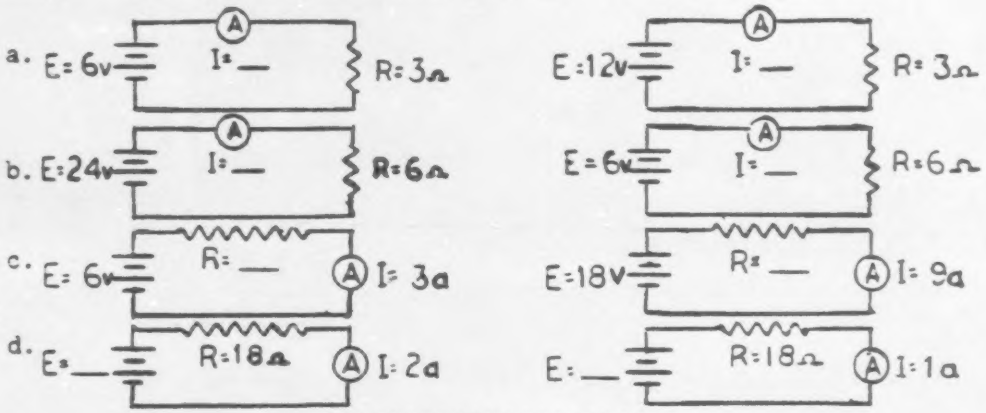
////////////////////

Proceed to the next frame.

Frame 97

What effect will a change in voltage have on current? If the applied voltage is increased with the resistance value remaining the same, current will also increase. Isn't this logical since the amount of opposition is still the same but we get more force to push current through this resistance? By the same token, if applied voltage is decreased, the current decreases also.

In the following diagram fill in the missing values to reflect the effect of a change in one value and its effect on the other two values.



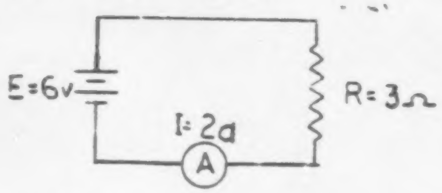
////////////////////

a. I = 2a I = 4a
b. I = 4a I = 1a
c. R = 2 Ω R = 2 Ω
d. E = 36v E = 18v

Frame 98

Does a change in voltage affect resistance? Well, just what is resistance? You remember, I'm sure that resistance is the opposition to current flow. If this is true, how can voltage have any effect on resistance? Since a resistor is a component which has a fixed value of resistance, unless it becomes damaged, it will continue to offer the same value of resistance, regardless of the amount of voltage.

For example, let's use the same circuit which was illustrated in Frame 95. We have a 3 Ω resistor through which 2a of current is flowing with 6v applied. Now, if we change the 6v to 12v this does not change the amount of resistance caused by the 3 Ω resistor.



//////////////////////

No Response Required

Frame 99

So you noticed from the statement in the preceding frame that although resistance remained unchanged something happened to current. This is what we said a few frames ago; the change in voltage will cause a change in current. So instead of there being 2a of current which we originally had with 6v applied, now with 12v applied the current has increased to 4a.

Place a T in the space beside the true statement(s).

_____a. When the voltage decreases current increases.

_____b. When current increases resistance also increases.

_____c. If voltage increases resistance remains the same.

_____d. If resistance increases voltage increases.

//////////////////////

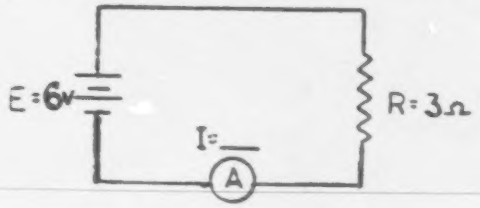
c

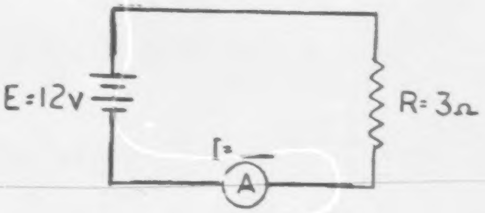
Frame 100

Up to now we've learned that with a change in voltage current must also change, but resistance is not affected by this change in voltage. Supposing though, instead of voltage changing one of the other quantities (I or R) should change. What effect would this have on the other values? Let's take current first. The only way to have a change in current is for either E or R to change in value. Also the only way to have a change in resistance is for either E or I to change. Let's go back to our example which we used in Frames 95 and 98. We found in Frame 98 that with a change in voltage we got an increase in current with resistance remaining the same. Let's say that instead of current changing with an increase in voltage, we find that resistance has increased. This would be because the current flow remained at the same value. With 12 volts applied to the circuit and with 2a of current flow, there would have to be 6Ω of resistance. Anytime the resistance in a simple circuit changes with voltage remaining the same, there must be a change in current. By applying Ohm's Law and using the memory device, we can solve for these unknown values.

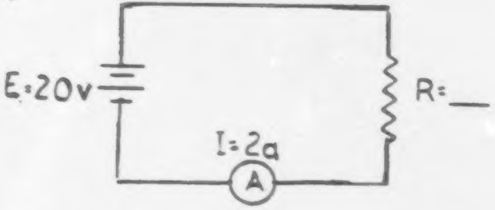
Solve for the missing values in the circuits which follow by first drawing the memory device and, from this, select the proper formula to use.

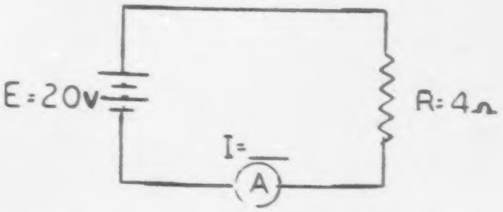
a.



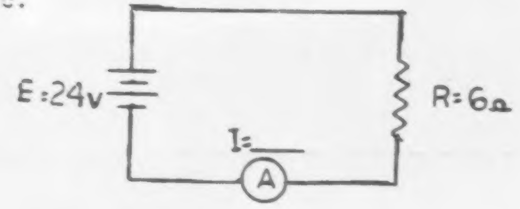


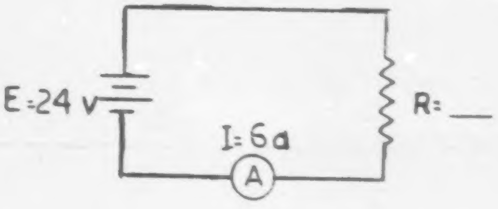
b.



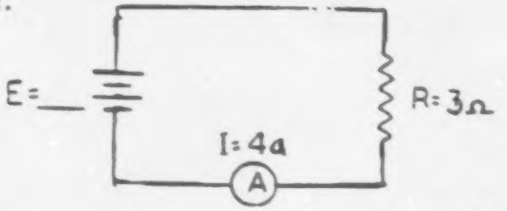


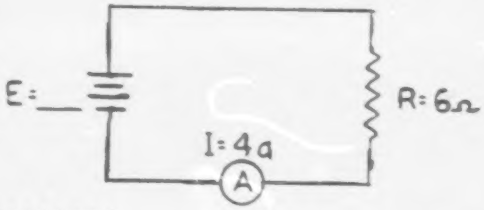
c.





d.

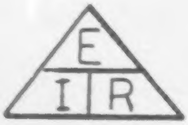




////////////////////

a. I = 2a I = 4a c. I = 4a R = 4Ω

b. R = 10Ω I = 5a d. E = 12v E = 24v



Frame 101

1. An increase in current can be caused by an (an) ____________________
(increase, decrease)
in voltage or a (an) ____________________ in resistance.
(increase, decrease)

2. If the value of R increased, the current in a circuit would
____________________.
(increase, decrease)

3. While an increase in voltage will cause an increase in current, this same increase in voltage ______________ affect resistance.
(will, will not)

4. Since resistance has the opposite effect on current, by decreasing resistance we will cause the amount of current to ____________________.
(increase, decrease)

5. Current in a circuit can be changed by (select the best one):

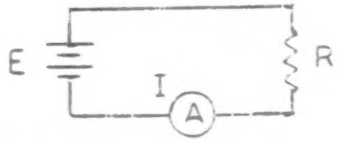
a. a change in voltage
b. a change in resistance
c. both of the above

///////////////////////

1. increase, decrease 2. decrease 3. will not
4. increase 5. c

Frame 102

The current in the circuit shown below should be 1.5 amperes. Upon measuring the current, the ammeter indicates two amperes. If the resistor (R) has not changed its value, the increase in current must be due to a (an) ____________________ in ____________________.



///////////////////////
increased in voltage.

Frame 103

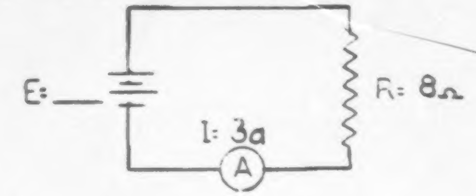
INSTRUCTIONS:

This frame contains three problems. You are to find the missing quantities by using Ohm's Law. Solve these problems using the procedure outlined below:

a. identify the unknown.
b. select the proper formula to find that unknown.
c. insert the knowns (givens) into the formula and solve.
d. express the correct answer using the correct unit.

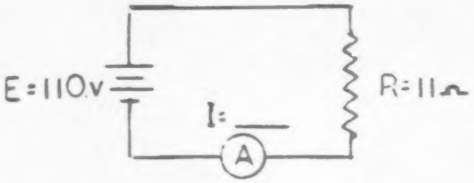
1. Given:
   I = 3a
   R = 8 Ω

   Find:
   E = ______



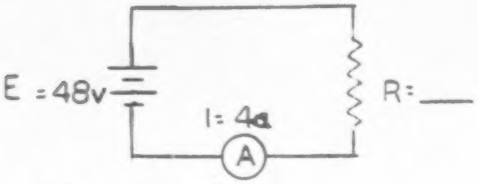
2. Given:
   E = 110v
   R = 11 Ω

   Find:
   I = ______



3. Given:
   E = 48v
   I = 4a

   Find:
   R = ______



//////////////////////

1. Unknown: E
   Formula: E = I x R
   Known: I = 3a, R = 8Ω
   E = 24v

2. Unknown: I
   Formula: I = E/R
   Known: E = 110v,
   R = 11Ω
   I = 10a

3. Unknown: R
   Formula: R = E/I
   Known: E = 48v,
   I = 4a
   R = 12Ω

Frame 104

If the current in a circuit is four amperes when it should be five amperes, you can suspect either an increase in ______________ or a decrease in ______________.

//////////////////////

resistance, voltage

This completes the Programmed Instructional Package on Principles of Electricity. Consult your instructor for further instructions.

190

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PROGRAMMED INSTRUCTION

2-5

Basic Electricity
Review

Part I

MATTER

Aviation Training Division
USCG - AR&SC - Elizabeth City, N. C.

BASIC ELECTRICITY REVIEW

PART I

MATTER

INSTRUCTIONS

This is a programmed lesson. It is designed to teach, not to test. You will need only this booklet, a pencil, and some time to complete this lesson. If there is something in the program you do not understand, ask your instructor or supervisor for assistance.

- REMEMBER -

This lesson has been written so that the amount of reading necessary is minimal and yet most meaningful. Therefore, it is very important that you follow these instructions.

- Read each page carefully.
- Fill in each blank.
- Keep the answer to the frame on which you are working covered with a slip of paper until you have written your answer.
- Correct all errors you make.
- Follow all directions given in the program.

SUGGESTED READING TIME
105 MINUTES

BASIC ELECTRICITY REVIEW

PART I

MATTER

OBJECTIVES

1. Given a list of definitions pertaining to the words listed below, match each word to its proper definition.

    a. Matter

    b. Mass

    c. Volume

    d. Density

    e. Weight

    f. Porosity

    g. Inertia

    h. Impenetrability

2. For a given body of matter, state what happens to its mass if its location, volume, or state is changed.

3. Given the volume and weight of a body, determine its density.

4. State what effect the distance an object is from the surface of the earth has on the weight of the object.

5. State the results of matter having the property of porosity.

6. List three examples of the inertia of objects (balls, aircraft, vehicles) being overcome.

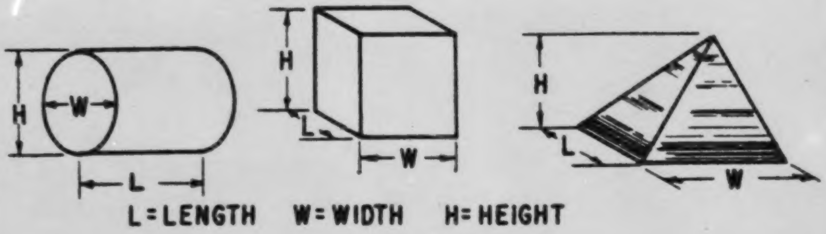
7. List the three states of matter.

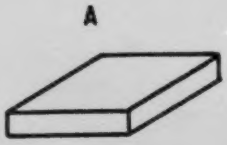
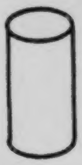
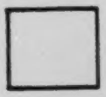
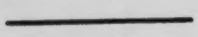
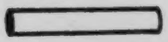
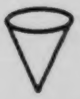
8. Select from a list of the characteristics of matter those characteristics pertaining to each state of matter.

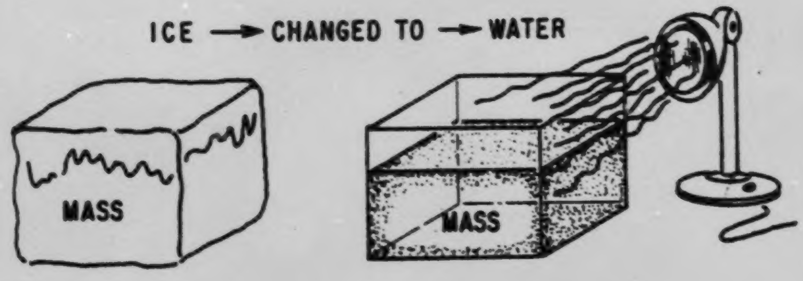
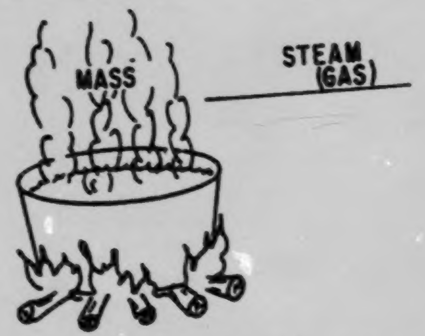
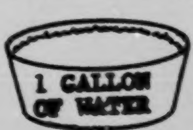
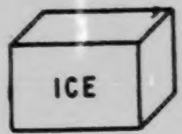
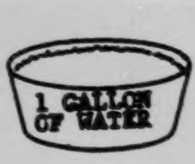
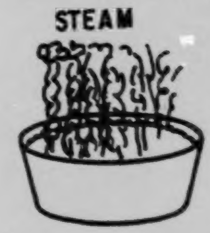
INTRODUCTION

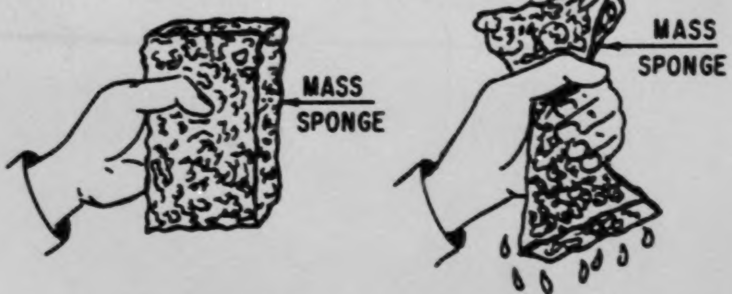
To understand electricity, hydraulics, carburetion, the operation of a jet engine, and the operation of a reciprocating engine, you must have a basic knowledge of physics.

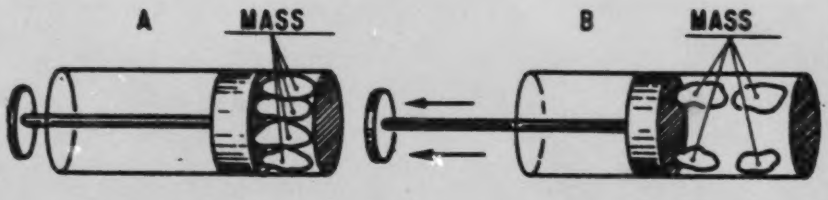
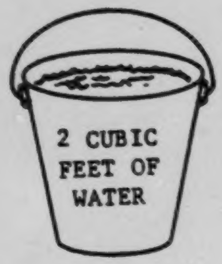
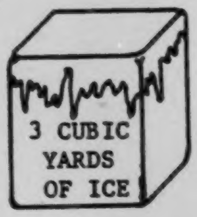
This program will provide you with a basic foundation in simple physics. With a complete understanding of this lesson, it will be easier for you to do more advanced study in the field of physics. Read this material carefully. For more information in this area, refer to the 1964 edition of "Modern Physics" by Metcalfe, Williams, and Dull.

	1. The universe contains nothing but matter. The sun and a particle of dust are parts of the universe; therefore, each is an example of ____________.
MATTER	2. Everything in the universe is composed of matter. Underline the items below that are matter. a. Truth b. Rock of Gibraltar c. Freedom d. Air e. A tree
b. ROCK OF GIBRALTAR d. AIR e. A TREE	3. The chair in which you are setting, the pencil with which you are writing, and the page of the book you are reading are all examples of ____________.
MATTER	4. Since everything in the universe has weight and occupies space, matter can be defined as anything that has __________ and occupies __________.
WEIGHT SPACE	5. Define matter. ______________________________ ______________________________ ______________________________
ANYTHING THAT HAS WEIGHT AND OCCUPIES SPACE.	6. All matter has the property of volume. Since matter has volume, it will have three dimensions.  H W L H L W H L W L=LENGTH W=WIDTH H=HEIGHT The dimensions that give matter the property of volume are __________, __________, and __________.

LENGTH WIDTH HEIGHT	7. To have the property of volume, matter must have all three dimensions. Underline the illustrations that represent a body having volume. A  B  C  D  E  F 
A B E F	8. Matter is defined as anything that has weight and occupies space. By occupying space, it will have the property of ________________.
VOLUME	9. Matter also has ______________.
MASS	10. The mass of a given body does not change although its state (solid, liquid, gas) changes. If a given body is changed from a solid to a liquid, what will happen to the mass of the body? ______________________________________

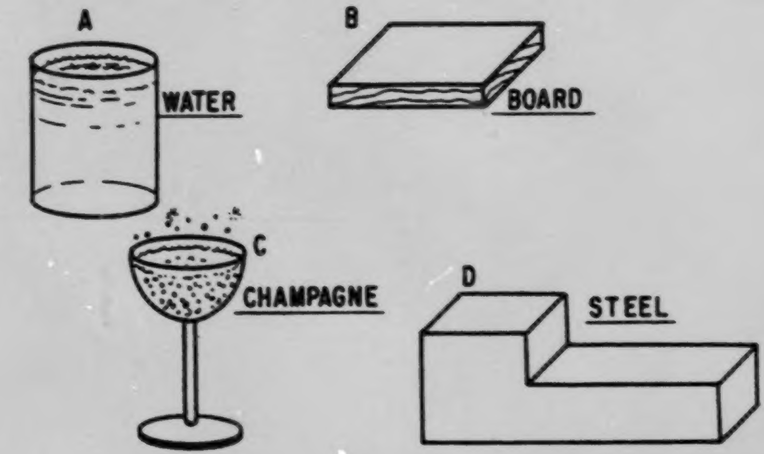
REMAINS UNCHANGED. (OR EQUIVALENT)	11.  ICE → CHANGED TO → WATER MASS MASS In the illustration above, the mass of the body ______________ change. (did/did not)
DID NOT	12.  MASS STEAM (GAS) The state of the water (liquid) has now been changed to steam (gas). What has happened to its mass? ________________________________
REMAINED THE SAME.	13. Mass is the amount of matter a given body contains. If  1 GALLON OF WATER is frozen into , then melted into  1 GALLON OF WATER, then heated to form , the matter has been changed to the three different states. In all three states, the body of matter contained the same ____________________.

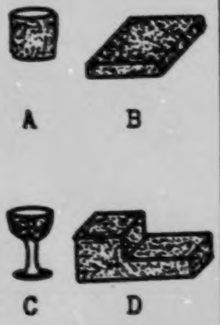
MASS	14. The amount of matter a given body contains is its ________.
MASS	15. Mass is the ________________________________ ________________________________ ________________________________.
AMOUNT OF MATTER A GIVEN BODY CONTAINS	16. A gallon of paint, which has a certain mass, is carried from the basement to the second floor of a building. The location of the paint has been changed. What has happened to its mass? ________________________________
REMAINED UNCHANGED. (OR EQUIVALENT)	17. A baseball hit by a batter to an outfielder would have the same mass when caught as when hit. If this baseball could be hit to the moon, its mass would remain ________________.
UNCHANGED (OR EQUIVALENT)	18. The mass of a body ____________ (is/is not) affected by changing its location.
IS NOT	19. When the state or location of a given body is changed, the mass will remain ____________.
CONSTANT (OR EQUIVALENT)	20. When the volume of a given body changes, the mass of that body remains the same.  In the illustration above, the mass of the sponge remains constant, although the volume has ________________ (increased/decreased).

DECREASED	21.  In item A, the piston is in; in item B, it is out. Going from illustration A to illustration B, the volume has ________________, while mass has ________________ ________________.
INCREASED REMAINED CONSTANT	22. Define mass. ________________________________ ________________. When the location, state, or volume of a given body is changed, its mass will ________________.
THE AMOUNT OF MATTER A GIVEN BODY CONTAINS REMAIN CONSTANT	23.   Volume is the space mass occupies. In the illustrations above, the bucket contains ____ ________ feet of water, and there are ____ __________ yards of ice. These are measurements of the volume of the two masses. Volume is always measured in __________ units.
2 CUBIC 3 CUBIC CUBIC	24. The space mass occupies is its ________________.
VOLUME	25. A tank contains 2 cubic feet of gas; this is a measure of the ________________ of the gas.

VOLUME

26. Shade the volume of the mass in each of the following:





27. Volume is the ______________________________

____.

SPACE THAT MASS OCCUPIES

28. The density of a body is the weight per cubic unit of its volume. For example, the density of fresh water is 62.5 pounds per cubic foot.

The density of a body is found by dividing its weight by its volume:

$$\text{Density} = \frac{\text{Weight}}{\text{Volume}} \quad \text{or} \quad D = \frac{W}{V}$$

Use the formula above to solve the following problem.

Two cubic feet of salt water has a weight of 128 pounds. What is the density of salt water?
NOTE: Density must be expressed in weight per cubic unit.

$D = \frac{W}{V}$

$D = \frac{128}{2}$

D = 64 POUNDS PER CUBIC FOOT

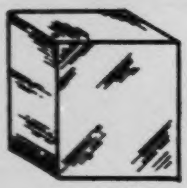
29. Dividing the weight of a body by its volume will give you the ________________ of that body.

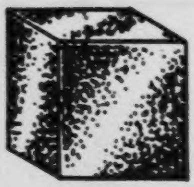
DENSITY

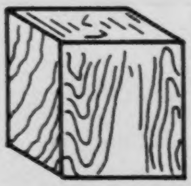
30. Density is the weight of a unit volume of matter. Iron has a greater density than wood. This means that one cubic foot of iron weighs more than one cubic foot of wood. The more matter (mass) there is in a given volume of a substance, the greater the density of the material.

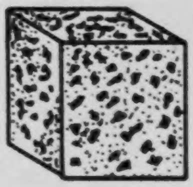
Shown below are some examples of the density of different materials. Circle the item that has the greatest density.

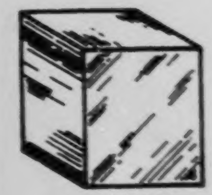
DENSITIES IN POUNDS PER CUBIC FOOT


LEAD
705


IRON
475

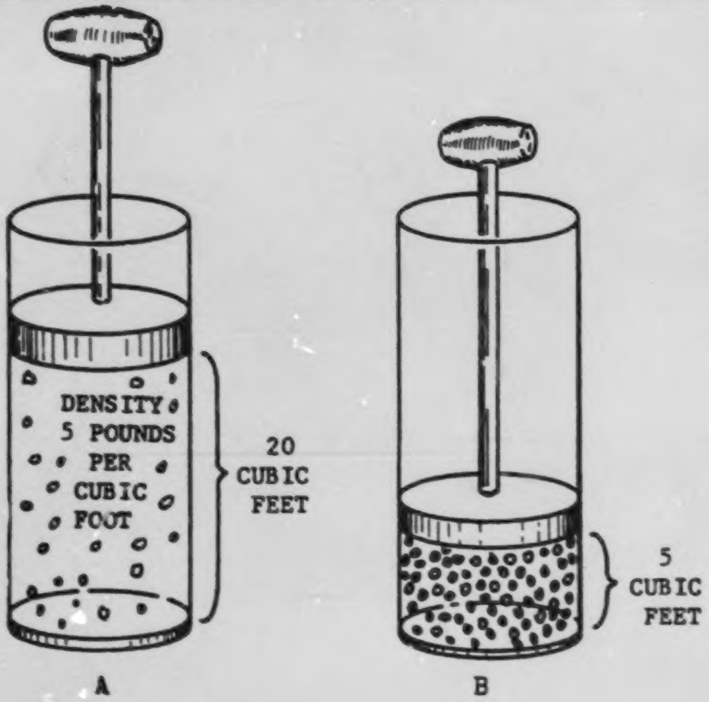
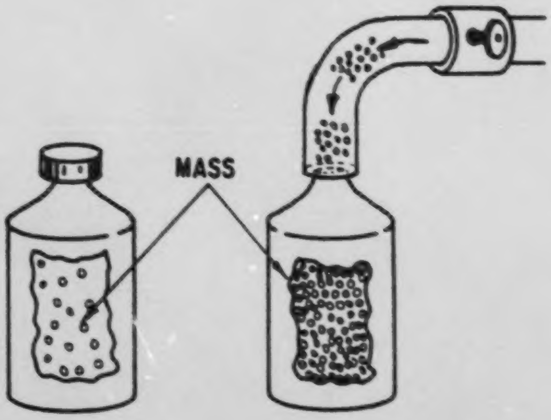

MAPLE
45

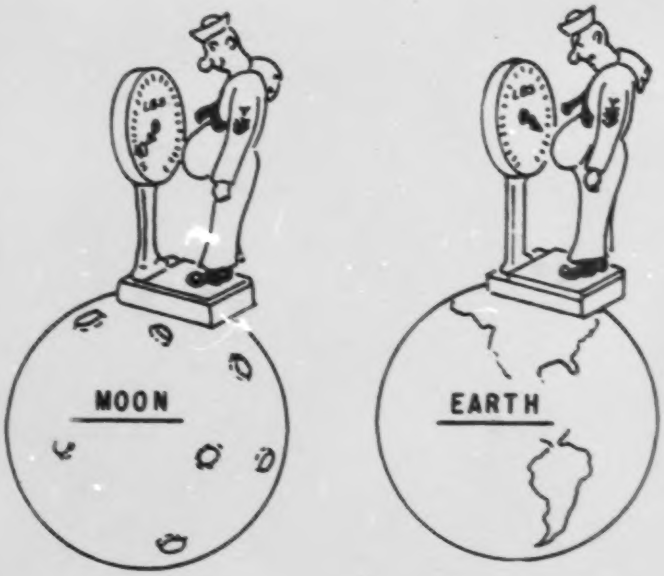

CORK
15


LEAD
705

31. A tank with a volume of 32 cubic feet is filled with a fluid weighing 1280 pounds. What is the density of this fluid? NOTE: Density must be expressed in weight per cubic unit.

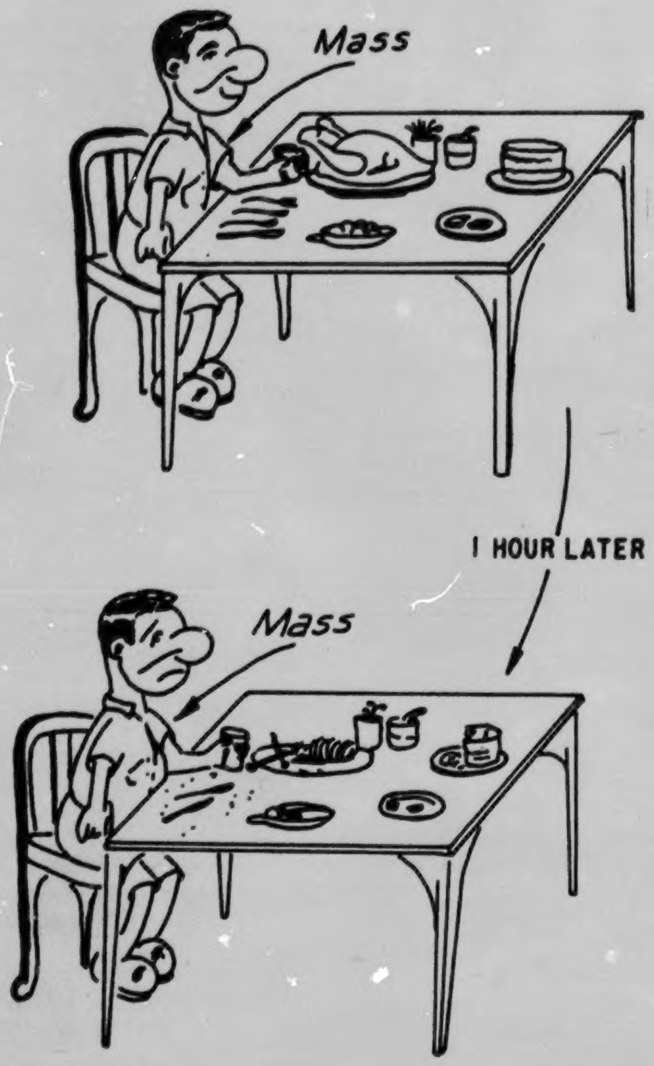
$D = \frac{W}{V}$ $D = \frac{1280}{32}$ D = 40 POUNDS PER CUBIC FOOT	32. When volume and density are known, the total weight of a body can be found by transposing the formula in this manner: WEIGHT = DENSITY × VOLUME (OR) $W = D \times V$ - Solve this problem - A tank contains 10 cubic feet of salt water. What is the total weight of the salt water? NOTE: The density of salt water is 64 pounds per cubic foot.
$W = D \times V$ $W = 64 \times 10$ W = 640 POUNDS	33. A tank with a volume of 100 cubic feet is filled with a gas which has a density of 4 pounds per cubic foot. What will be the density of this gas if it is compressed to a volume of 2 cubic feet? To solve for the new density, follow the steps below and fill in all blanks. STEP (1) Find the total weight of the gas. $W = D \times V$ $W = 4 \times 100$ W = _______ pounds STEP (2) To determine the new density, divide the weight of the gas by its new volume (2 cubic feet). $D = \frac{W}{V}$ $D = \frac{400}{2}$ D = _________ pounds per cubic foot Circle the number beside the statement that is correct for the problem above. a. As volume decreased, density decreased. b. As volume decreased, density increased. c. As volume decreased, density remained the same.

W = 400 D = 200 b. AS VOLUME DECREASED, DENSITY INCREASED.	34.  DENSITY 5 POUNDS PER CUBIC FOOT 20 CUBIC FEET 5 CUBIC FEET A B A gas with a density of 5 pounds per cubic foot has a volume of 20 cubic feet, as in item A above. What is the density of the gas after it has been compressed as in item B? ____________________
20 POUNDS PER CUBIC FOOT	35.  As the bottle is filled with gas, the mass will increase but the volume will remain the same, while the weight and density will ____________________. (increase/decrease)

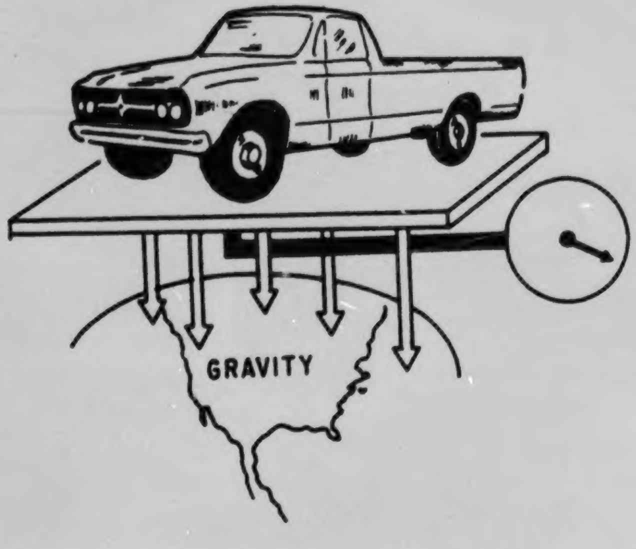
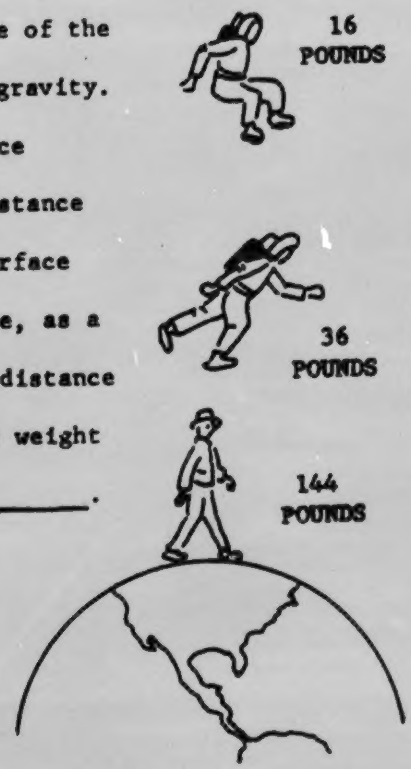
INCREASE	36. Two cubic feet of mercury have a weight of 1692 pounds. What is the density of mercury? ______________________________
846 POUNDS PER CUBIC FOOT	37. Place a check mark by the correct statement. ____ a. Density is the amount of mass a given body contains, and the formula for finding density is $D = \frac{V}{W}$. ____ b. Density is weight per unit volume, and the formula for finding density is $D = \frac{W}{V}$. ____ c. Density is weight per unit volume, and the formula for finding density is $W = D \times V$.
b.	38. The gravitational pull of the earth is six times greater than the gravitational pull of the moon.  How much will the man on the moon weigh if he is moved from the moon to the earth? ________ pounds

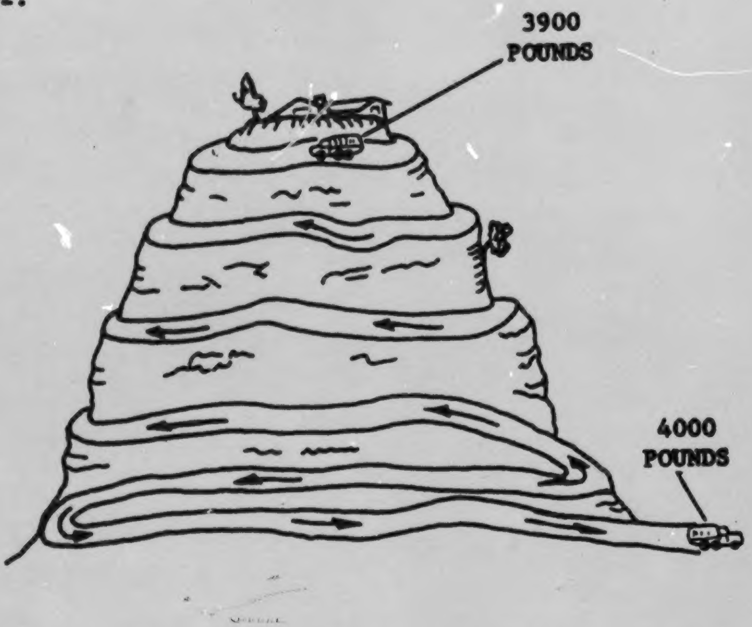
240 POUNDS

39. An increase in mass will cause an increase in gravitational pull.


Mass
1 HOUR LATER
Mass

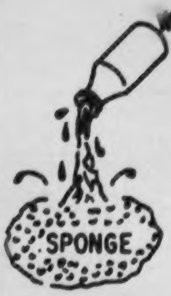
In the illustration above, the mass of the man has ________________. This has caused a(n) ________________ in his weight.

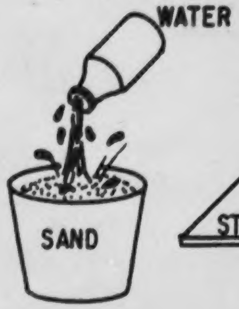
INCREASED INCREASE	40.  Weight is a measure of the effect of ____________ on a body.
GRAVITY	41. The attractive force of the earth on matter is gravity. This attractive force decreases as the distance from the earth's surface increases; therefore, as a body increases its distance from the earth, its weight will __________________.  16 POUNDS 36 POUNDS 144 POUNDS

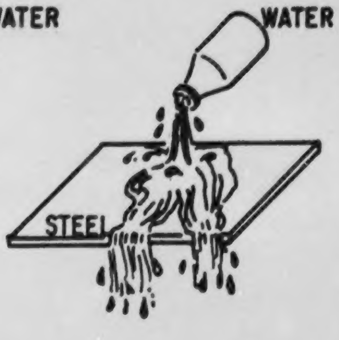
DECREASE	42.  Compare the weight of the body (car) at sea level with its weight on top of the mountain. At which point does it weigh the more? ________________
SEA LEVEL	43. Weight is a measure of ____________________ ____________________________________ ____________________________________.
THE EFFECT OF GRAVITY ON A BODY	44. Another property of matter is universal attraction. This means that all matter attracts all other matter. All matter attracts all other matter. This is the property known as ____________ ____________.

UNIVERSAL ATTRACTION

45. Another property of matter is porosity.

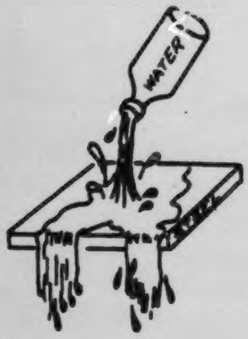

WATER
SPONGE



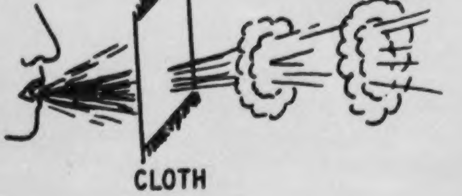

WATER
STEEL

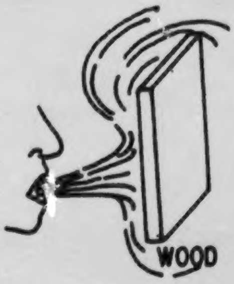
Some matter is more porous than others.

In the illustration above, circle the matter that will absorb the smallest amount of water.



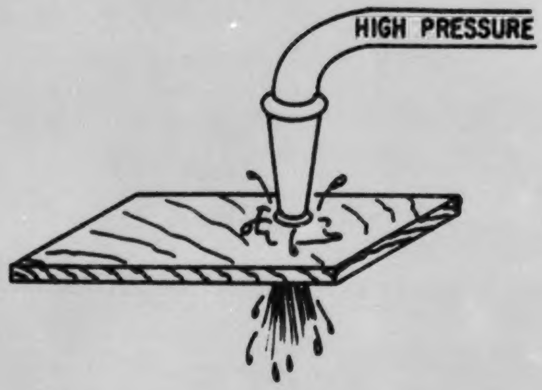
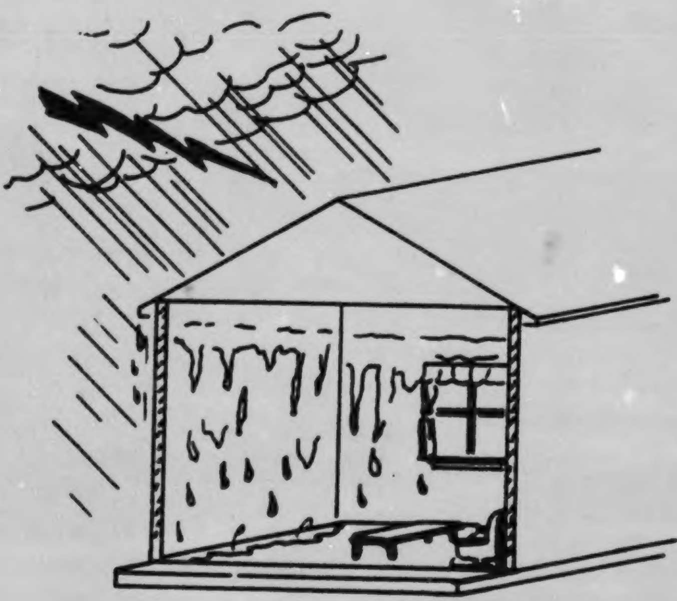
46.





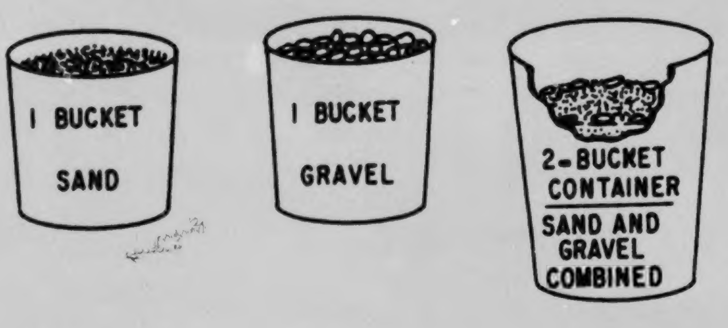
In the illustration above, the smoke will travel through the cloth because it has more space between its particles. The smoke will not travel through the wood because it has less __________

______________________________________.

SPACE BETWEEN ITS PARTICLES	47.  All matter has the property of porosity. We normally think of steel, or even wood, as being very solid; but water, under high pressure, can be forced through their minute openings because they have the property of ____________.
POROSITY	48.  "Mama, get the mop, because these walls have the property of _________________."

POROSITY

49. Porosity permits two substances to be combined and occupy less space than both would occupy separately.


1 BUCKET
SAND
1 BUCKET
GRAVEL
2-BUCKET CONTAINER
SAND AND GRAVEL COMBINED

What does the illustration above show is possible since matter has the property of porosity?

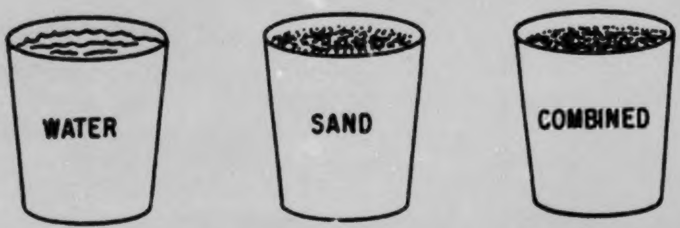
____

____

____

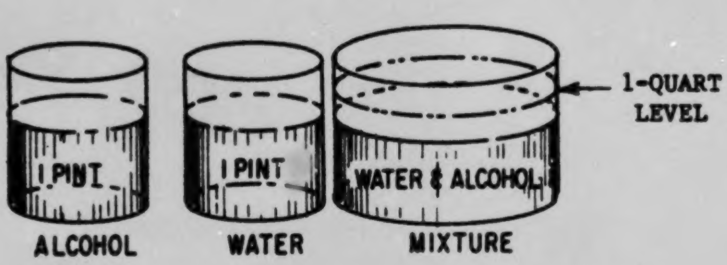
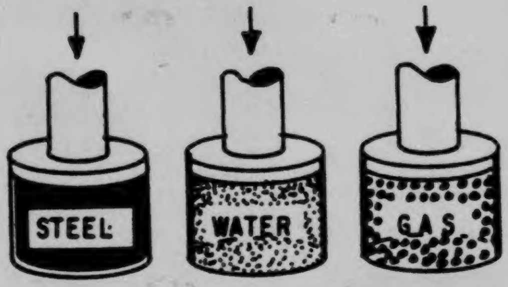
TWO SUBSTANCES CAN BE COMBINED AND OCCUPY LESS SPACE THAN BOTH OCCUPIED SEPARATELY.

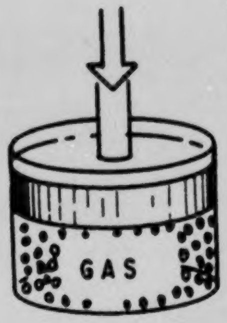
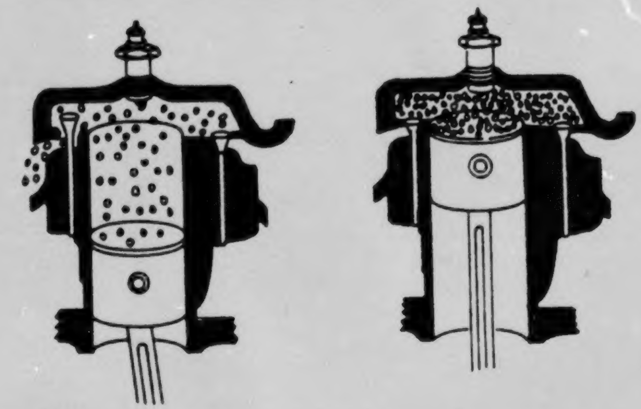
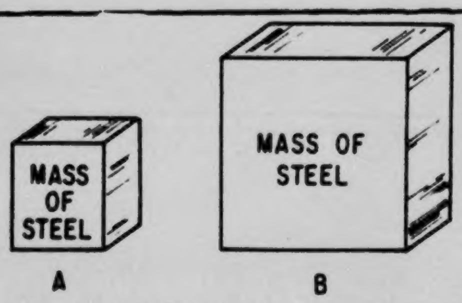
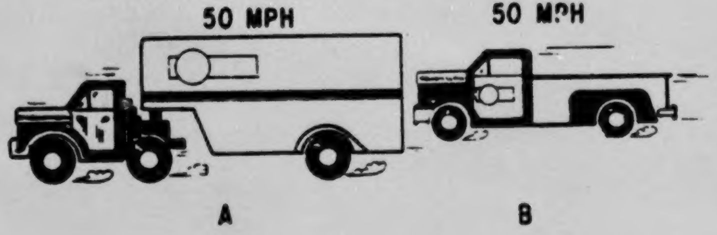
50. The space between the particles of one type of matter, which gives it the property of porosity, may be occupied by particles of another matter. The two will occupy less space when ____________.

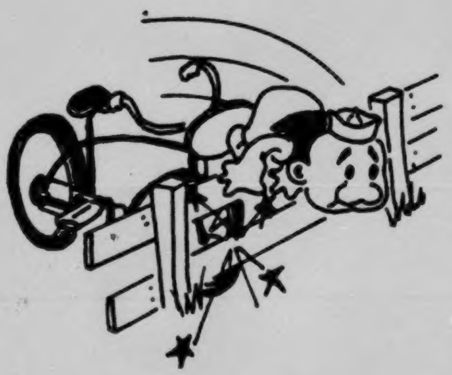

WATER
SAND
COMBINED

What makes it possible to pour a bottle of water into a bucket of sand without running it over?

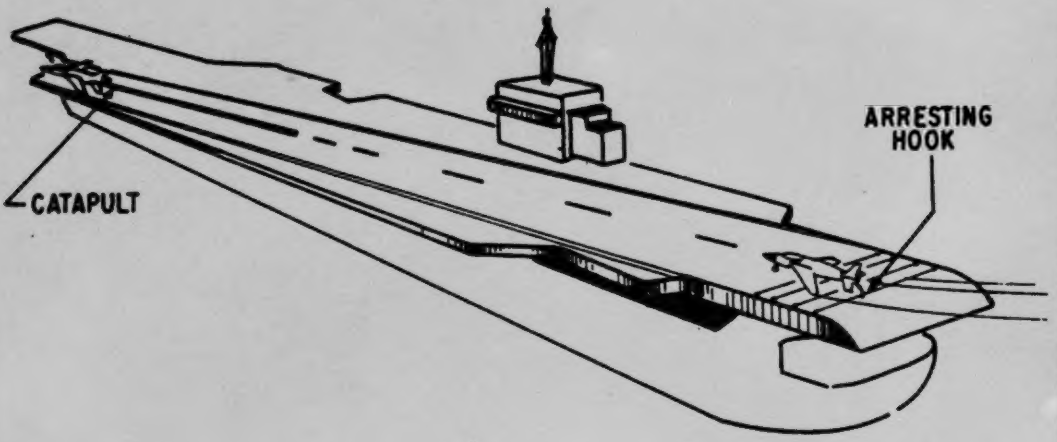
____

COMBINED POROSITY	51. All matter has space between its particles (molecules). This is what gives matter the property of porosity.  1 PINT 1 PINT WATER & ALCOHOL 1-QUART LEVEL ALCOHOL WATER MIXTURE Complete the statement below concerning the above demonstration. Porosity permits two substances to be combined and occupy less ____________ than both occupy ____________.
SPACE SEPARATELY	52. What gives matter the property of porosity? ____________________________________ ____________________________________
THE SPACE BETWEEN THE PARTICLES OF MATTER.	53. Porosity permits some matter to be compressed easier than others. Gas is matter that can be easily compressed. What property of matter permits this? ____________
POROSITY	54.  STEEL WATER GAS Circle the matter which is the easiest to compress.

	55.  What property of matter permitted the large volume of air to be taken into the cylinder and compressed? ______________
POROSITY	56. The amount of matter a given body contains is its __________.
MASS	57.  MASS OF STEEL MASS OF STEEL A B Which item above would require more force to move it (overcome its inertia)? _____
B	58.  50 MPH 50 MPH A B Which truck would require more force to overcome its inertia and stop it? _____

A	59. The more mass, the more force required to overcome its ________________.
INERTIA	60. The property of matter that requires an outside force to be applied to stop or start that matter is inertia. Inertia is the property of matter that requires an ______________ ______________ to be applied to stop or start that matter.
OUTSIDE FORCE	61. A body at rest will remain at rest unless acted upon by an outside force. A body in motion will remain in motion unless acted upon by an outside force.  What is required to stop the above man? ________________________________ What property of matter requires this? ______________
AN OUTSIDE FORCE. INERTIA	

62.

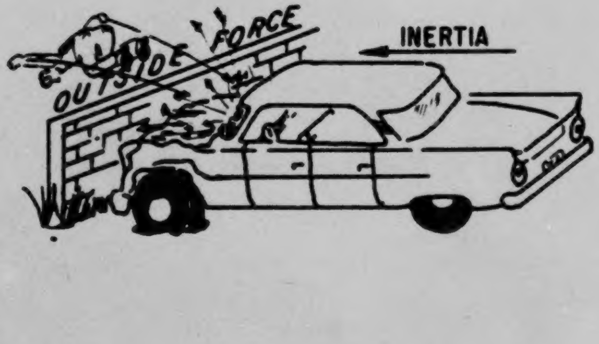

CATAPULT
ARRESTING HOOK

What two devices are being used to overcome the inertia of the above aircraft? a. ________________ b. ________________________

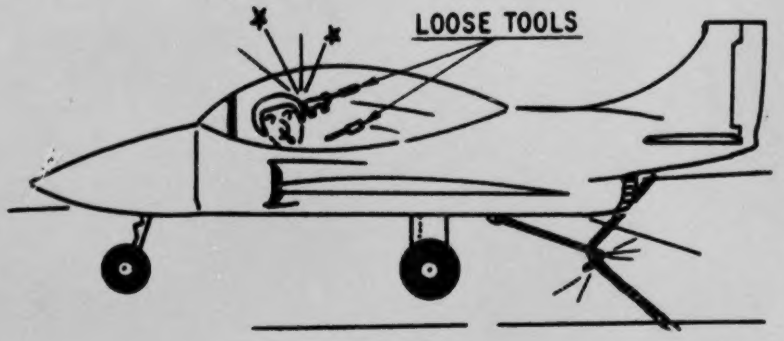
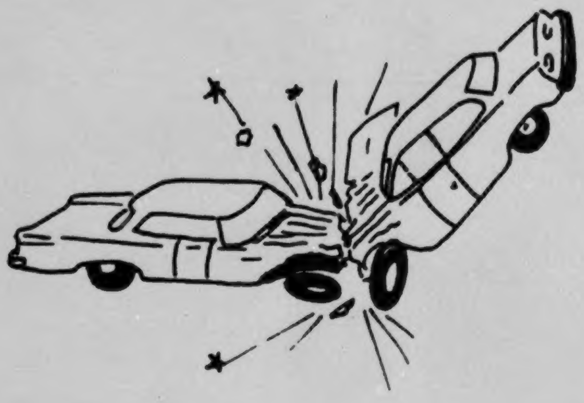
a. CATAPULT

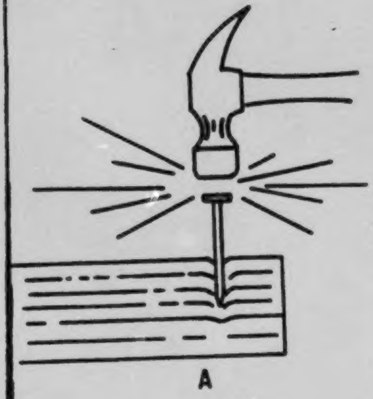
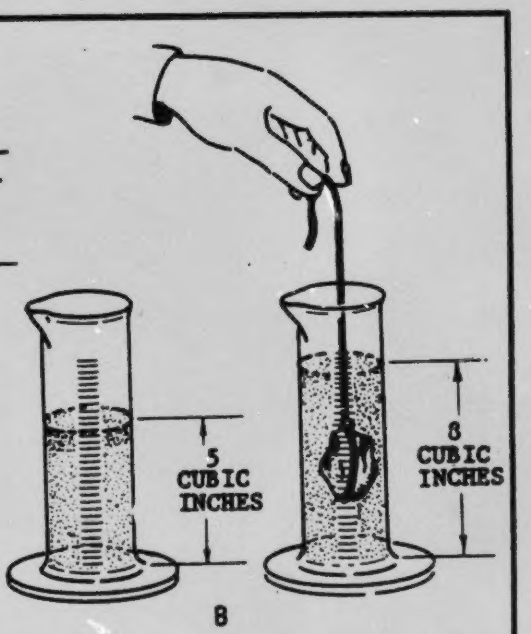
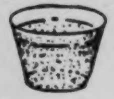
b. ARRESTING HOOK

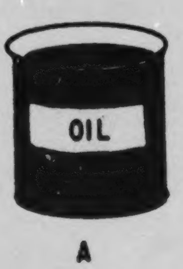
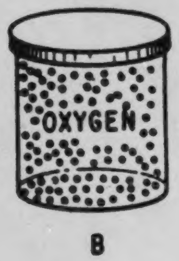
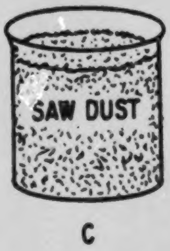
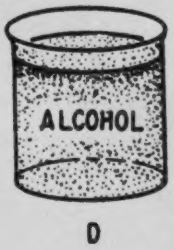
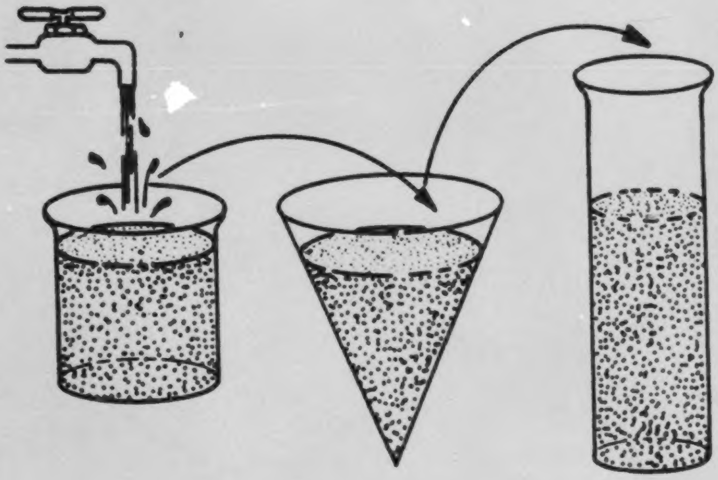
63.

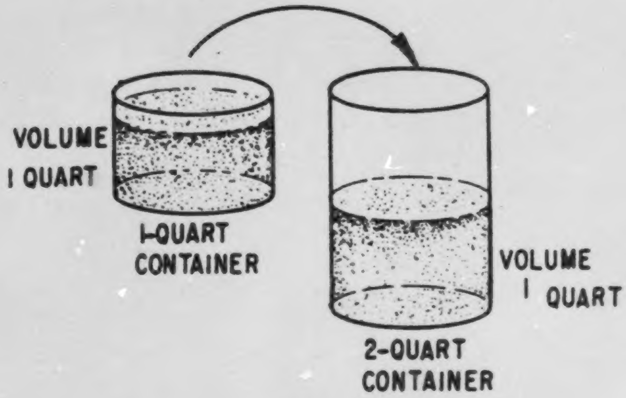
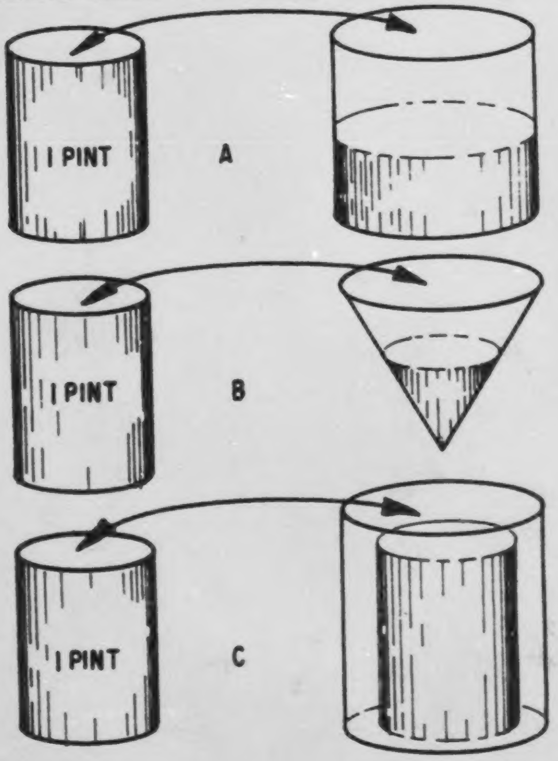

OUTSIDE FORCE
INERTIA

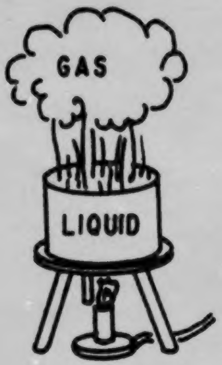
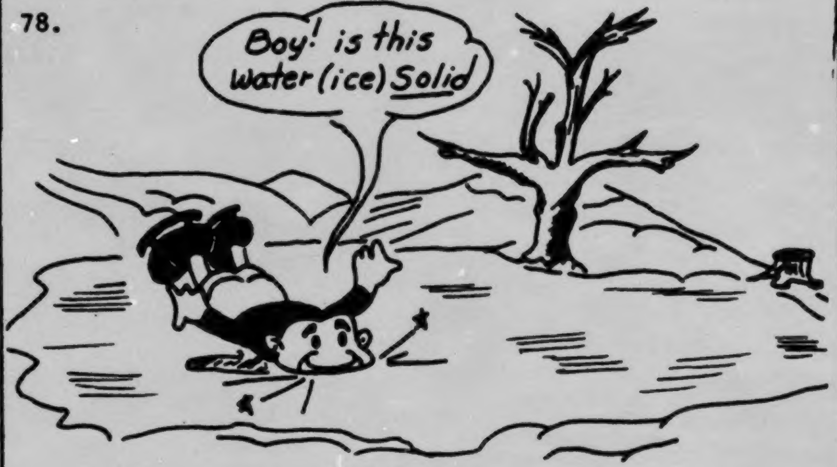
"Well, the property of ____________ has done it again."

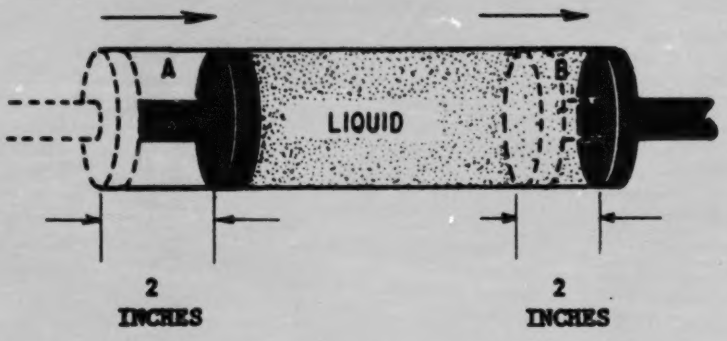
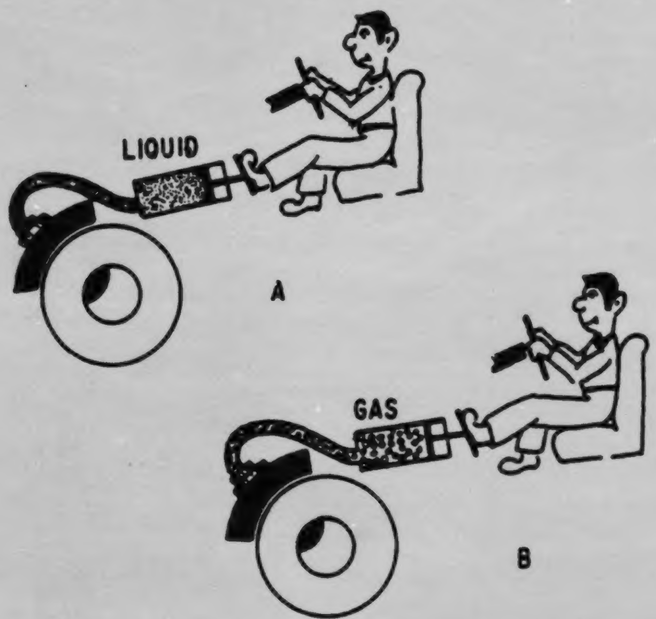
INERTIA	64.  What property of matter did the plane captain overlook? ________________
INERTIA	65. Matter cannot start or ___________ itself.
STOP	66. All matter possesses the property of impenetrability.  The two vehicles could not occupy the same space at the same time because they possess the property of ______________________________.

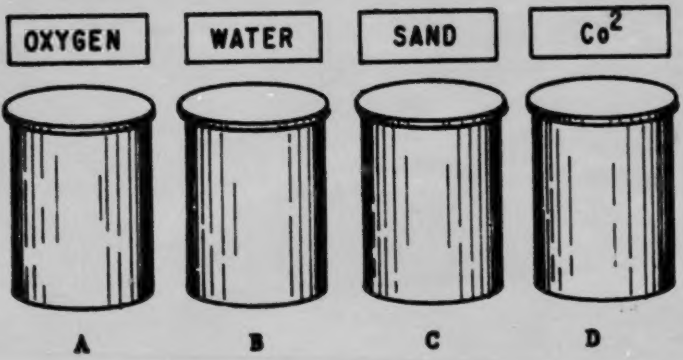
IMPENETRABILITY	67.   As the nail is driven into the wood, illustration A, the grains of wood will move aside. When the irregular-shaped object is placed in the container of fluid, illustration B, the fluid will rise an amount equal to the volume of the object. This is due to the fact that no two objects can occupy the same __________ at the same time. What is the volume of the irregular-shaped object? ______ CUBIC INCHES
SPACE 3 CUBIC INCHES	68. Impenetrability is the property of matter that will allow no two objects to ________________ ______________________________.
OCCUPY THE SAME SPACE AT THE SAME TIME	69. The states of matter are SOLID, LIQUID, and GAS. There are ________ (number) states of matter.
THREE	70. Matter may be a LIQUID.  What is the state of matter in the illustration? ______________

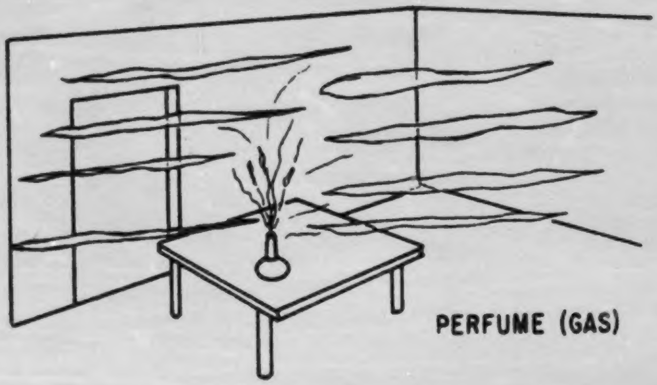
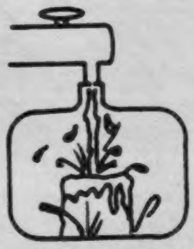
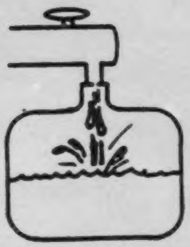
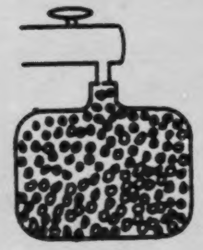
LIQUID	71.  A  B  C  D Circle the letter under the illustration(s) of a liquid.
A D	72. A fluid is matter that flows easily and requires a container in which to store it or keep it confined. Liquid is a ____________.
FLUID	73.  Liquid will assume the ______________ of the (volume / shape) container in which it is placed (see illustration).

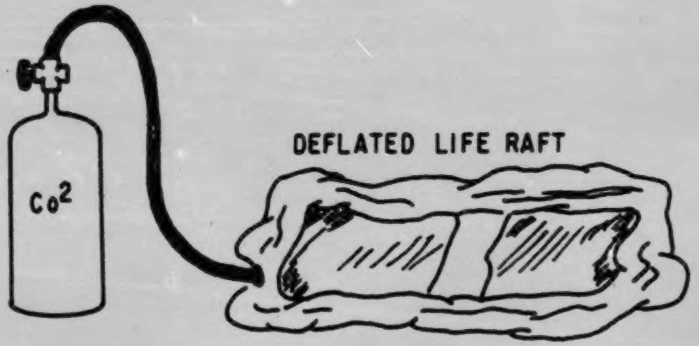
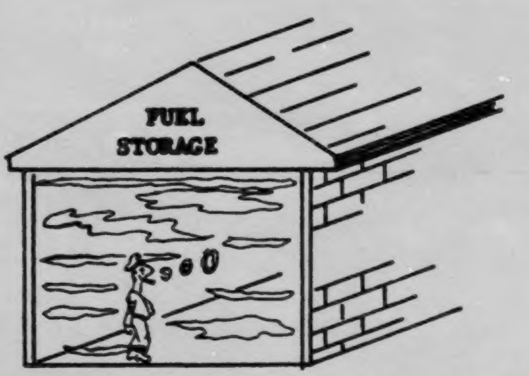
SHAPE	74.  VOLUME 1 QUART 1-QUART CONTAINER VOLUME 1 QUART 2-QUART CONTAINER A liquid, as indicated above, will not assume the ____________ of a larger container.
VOLUME	75.  1 PINT A 1 PINT B 1 PINT C Select the illustration(s) above which correctly represent(s) the transfer of a liquid from one container to another. ____________

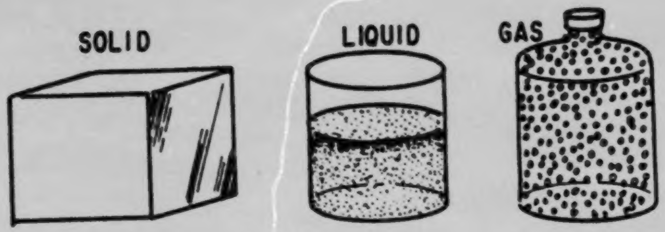
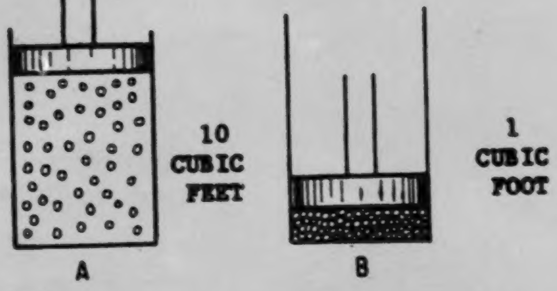
A B	76. A liquid will assume the ___________ of any container but will not assume the _____________.
SHAPE VOLUME	77.  As illustrated above, a liquid can be changed from a liquid to a ________.
GAS	78.  Boy! is this water (ice) Solid A liquid can be changed from a liquid to a ____________.
SOLID	79. Liquids can be changed to a ___________ or a ________________.

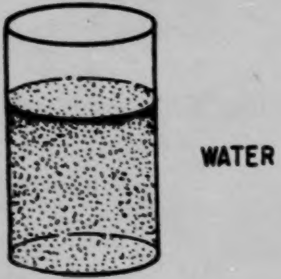
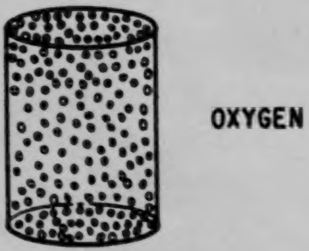
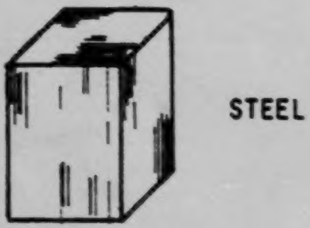
GAS SOLID	80. A liquid, for all practical purposes, cannot be compressed.  A B LIQUID 2 INCHES 2 INCHES When piston A moves 2 inches, piston B will move 2 inches. This is because liquids cannot be ________________________.
COMPRESSED	81.  LIQUID A GAS B Why will the person in illustration A get better braking action than the one in illustration B? ____________________________________ ____________________________________ ____________________________________

LIQUIDS, FOR ALL PRACTICAL PURPOSES, CANNOT BE COMPRESSED.	82. Select the characteristics of a liquid. a. Can be compressed. b. Is a fluid. c. Can be changed to a gas or a solid. d. Will assume the volume of any container. e. Will assume the shape of its container.
b., c., e.	83. Matter is anything that has weight and occupies space. Gas has weight and occupies space. Therefore, gas is ________________.
MATTER	84.  Circle the letter under the illustrations representing matter as a gas.
A D	85. A fluid flows easily and requires a container in which to store it; therefore, both liquids and gases are ________________.

FLUIDS	86. The molecules (particles) of a gas move freely as compared to those of a solid or liquid. All matter has movement of its molecules (particles); but, in comparison, the molecules of a ________ will move more freely than those of a solid or a liquid.
GAS	87.  PERFUME (GAS) What characteristic of a gas allows the molecules (particles) of the perfume to fill the entire room? ____ ____
THE MOLECULES IN A GAS MOVE FREELY.	88. Gas will assume the shape and volume of any container in which it is placed.  A  B  C Circle the illustration above that represents the transfer of a gas from one container to another.

C	89.  Co^2 DEFLATED LIFE RAFT What will happen to the shape and volume of the gas when it is released from the bottle into the life raft? ____ ____
IT WILL ASSUME THE SHAPE AND VOLUME OF THE LIFE RAFT.	90.  FUEL STORAGE Mr. Dilbert may soon be pushing up daisies because a gas will assume the __________________ and __________________ of its container.

SHAPE VOLUME	91. The space between the particles (molecules) of matter gives it the property of porosity. Some matter may be compressed because of the property of ____________________.
POROSITY	92.  SOLID LIQUID GAS If you could see the molecules (particles) in matter, as indicated above, the molecules would be very far apart in the ________.
GAS	93. A gas ______________ (can/cannot) be compressed.
CAN	94.  10 CUBIC FEET 1 CUBIC FOOT A B The illustrations indicate that a gas can be ____________________.

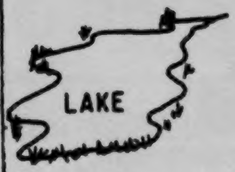
COMPRESSED	95. Select the characteristics of a gas. a. May be compressed. b. Will assume the shape of its container. c. Has molecules that are solidly fixed. d. Will assume the volume of any container. e. Does not have weight. f. Is a fluid.
a., b., d., f.	96. There are three states of matter.  Matter may be a ________________.  Matter may be a ________________.  Matter may be a ________________.

LIQUID

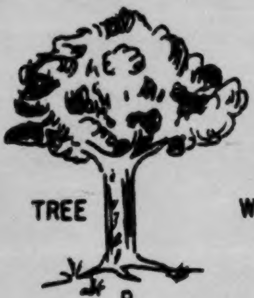
GAS

SOLID

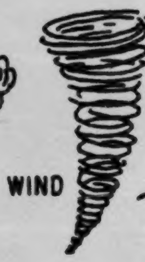
97.



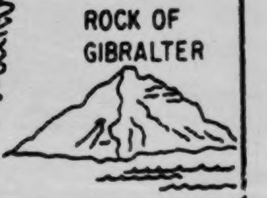
A



B



C

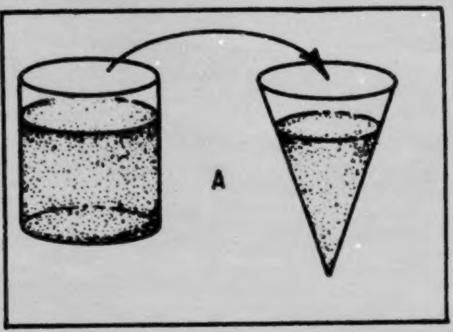

ROCK OF
GIBRALTER

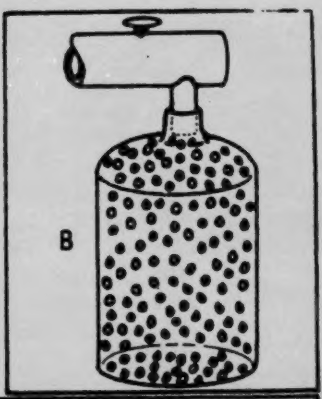
D

Circle the illustrations above that represent examples of solids.

B D

98.





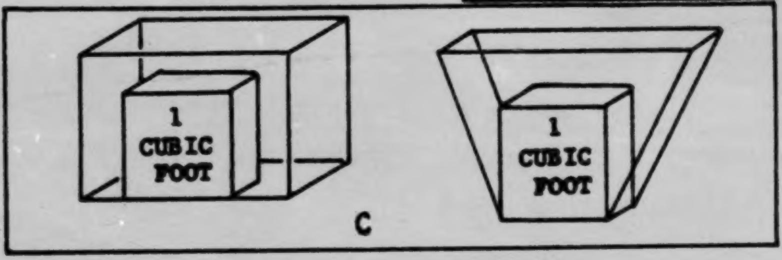
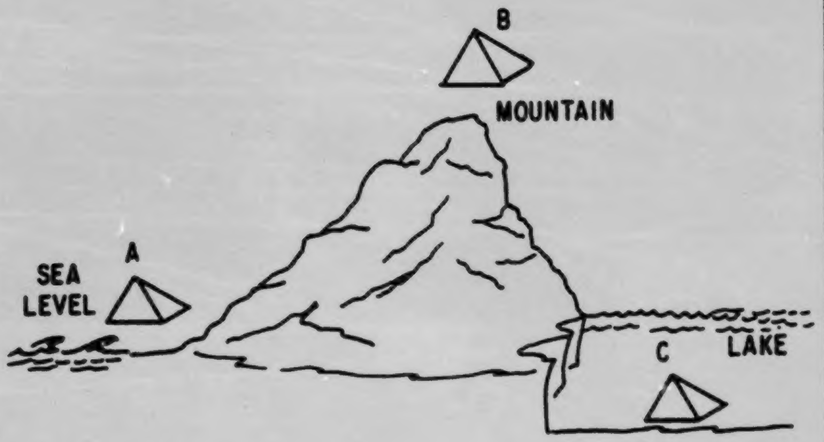

1
CUBIC
FOOT
1
CUBIC
FOOT
C

Illustration A: When a liquid is moved from one container to another, it will assume the shape of the new container but not its volume.

Illustration B: When a gas is moved from one container to another, it will assume the shape and volume of the new container.

Illustration C: When a solid is moved from one place to another, it will maintain the same ______________ and ________________.

SHAPE VOLUME	99. Solids have a definite shape. The shape of a solid is not changed when moved from one place to another This is because the molecules of solids are close together and are more fixed. A solid differs from a liquid or a gas in that the molecules are ____________ ______________ and are close ____________________.
MORE FIXED TOGETHER	100.  As illustrated above, a solid moved from SEA LEVEL to the top of a MOUNTAIN and then to the bottom of a LAKE will retain its shape and volume because its molecules are ____________________________ ___________________________________.
MORE FIXED AND CLOSE TOGETHER	101. Select the characteristics of a solid. a. Its shape is not changed when moved from one container to another. b. It can be compressed. c. Its particles are more fixed and are very close together.

a., c.

102. List the three states of matter in the blanks below. Below the blanks is a list of characteristics that pertain to these states when they are moved from one container to another. Place the number(s) found beside each characteristic under the state of matter to which it pertains.

a. ______________ b. ____________ c. _________

(1) Will assume the shape of its container.

(2) Will assume the volume of any container.

(3) Will maintain its shape and volume.

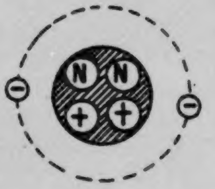
a. SOLID
(3)

b. LIQUID
(1)

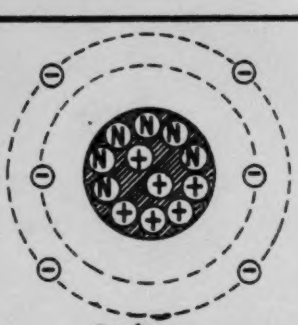
c. GAS
(1)(2)

PROTONS
NEUTRONS
ELECTRONS

31.



Helium.



Carbon.

The illustration above is an example showing that the numbers of protons (+), electrons (-), and neutrons (N) vary with the different kinds of atoms. Compare the number of protons (+), electrons (-), and neutrons (N) of the atoms above. Place the number of each in the space provided.

HELIUM		CARBON	
(+) Protons	_____	(+) Protons	_____
(N) Neutrons	_____	(N) Neutrons	_____
(-) Electrons	_____	(-) Electrons	_____

For the remainder of this program, instead of showing each individual neutron and proton in an atom, the total number of each will be shown.

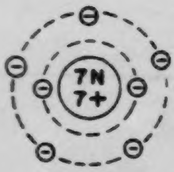
EXAMPLE: (6+) will indicate 6 protons and (6N) will indicate 6 neutrons.

HELIUM
(+) 2
(N) 2
(-) 2

CARBON
(+) 6
(N) 6
(-) 6

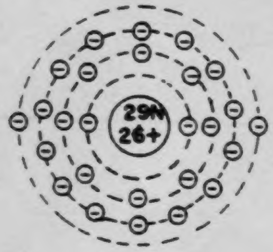
32. Each of the different atoms is identified by an atomic number (1 through 103). The number of protons in an atom determines its atomic number.

A



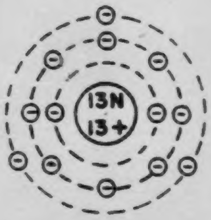
Nitrogen.

B



Iron.

C



Aluminum.

What is the atomic number of each of the above atoms?

A. ____________ B. __________ C. ___________

5. What is the formula for finding the density of a body?

6. A body weighs 2400 pounds and has a volume of 24 cubic feet; what is its density?

7. Ten cubic feet of gas with a density of 5 pounds per cubic foot are compressed to 2 cubic feet; what will the new density be

8. As an object's distance from the earth's surface is increased, the weight of that object will ____________________.

9. At which location will a given body weigh the more?

   a. On top of a mountain.
   b. At sea level.
   c. Weight would be the same at both a and b.

10. What property allows some matter to be compressed easier than others?

11. Give an example proving that matter has the property of porosity.

12. Inertia must be overcome in order to stop or start the movement of matter.

    What is required to do this? ______________________________

13. Give an example proving that matter has the property of impenetrability.

BASIC ELECTRICITY REVIEW

PART I

MATTER

SELF-TEST

1. Match each word in column A with its correct definition in column B by placing the letter found beside each word in the blank beside the appropriate definition.

A

a. Matter
b. Mass
c. Volume
d. Density
e. Weight
f. Porosity
g. Inertia
h. Impenetrability

B

____ That property of matter requiring an outside force to start or stop it.
____ Anything that has weight and occupies space.
____ No two bodies can occupy the same space at the same time.
____ It is the space that mass occupies.
____ The amount of matter a given body contains.
____ Weight per unit volume.
____ A property of matter that specifies there is space between the particles of matter.
____ A measure of the effect of gravity on a body.

2. Will the mass of a given body change if it is moved from sea level to 35,000 feet?

3. If one gallon of water is changed to steam, its volume will

a. decrease and its mass will decrease.
b. increase and its mass will increase.
c. increase and its mass will remain constant.

4. Which of the following is a measure of volume?

a. Square units
b. Cubic units
c. Linear units
d. None of the above
e. All the above

14. List three examples of the inertia of objects (balls, aircraft, vehicles) being overcome.

    a.
    b.
    c.

15. List the three states of matter in the blanks below. To the right is a list of characteristics that pertain to these states. Place the number found beside each characteristic under the state of matter to which it pertains. Some characteristics may pertain to more than one state.

    a. ________________ b. ________________ c. ________________

(1) Is a fluid.
(2) Will assume the shape of its container.
(3) May be compressed.
(4) Will assume the volume of any container.
(5) Shape is not changed when moved from one container to another.
(6) Particles are more fixed and very close together.

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PROGRAMMED INSTRUCTION

2-5

Basic Electricity
Review

ATOMIC STRUCTURE

Aviation Training Division
USCG - AR&SC - Elizabeth City, N. C.

BASIC ELECTRICITY REVIEW

PART II

ATOMIC STRUCTURE

OBJECTIVES

1. Given the terms compound, molecule, atom, mixture, ion, nucleus, and a list of the definitions of these terms, match each term to its definition.
2. Given an illustration of an atom, label its three parts.
3. Given an illustration of an atom, give the atomic number and the atomic weight of that atom.
4. Given some illustrations of atoms, label each as having a positive, negative, or neutral charge.
5. State the name given to electrons that have been removed from their orbit about an atom.
6. Compare a conductor and an insulator in relation to the number of free electrons that each contains.
7. State how electrical energy is transferred through a conductor.
8. State the direction the electrons flow when an atom with a negative charge is contacted by an atom with a positive charge.

BASIC ELECTRICITY REVIEW

PART II

ATOMIC STRUCTURE

INSTRUCTIONS

This is a programmed lesson. It is designed to teach, not to test. You will need only this booklet, a pencil, and some time to complete this lesson. If there is something in the program you do not understand, ask your instructor or supervisor for assistance.

- REMEMBER -

This lesson has been written so that the amount of reading necessary is minimal and yet most meaningful. Therefore, it is very important that you follow these instructions.

- Read each page carefully.
- Fill in each blank.
- Keep the answer to the frame on which you are working covered with a slip of paper until you have written your answer.
- Correct all errors you make.
- Follow all directions given in the program.

SUGGESTED READING TIME
75 MINUTES

INTRODUCTION

Electricity cannot be seen. No one can draw a picture of electricity nor can anyone capture a boxful of it. Electricity and the laws associated with it are theory. You will have to accept this theory, as science has done, before you can understand any of the rules or laws of electricity.

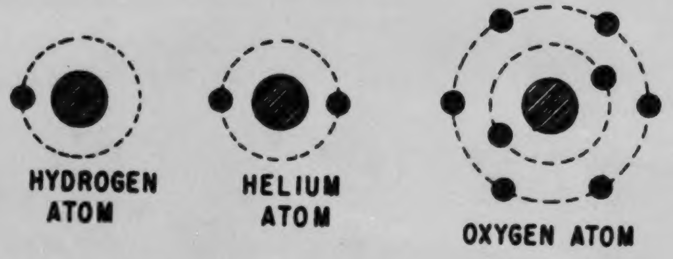
A basic understanding of the structure of the atom is necessary for you to understand what electrons are, how electrons flow, and why some materials resist this flow.

LIQUID	8. A compound will possess properties different from the properties of the elements used to make the compound. When two or more elements are combined chemically, a compound is formed which has different ____________ than its elements.
PROPERTIES	9. Sodium, an element, will ignite on contact with water, while the element chlorine is poisonous. A chemical combination of sodium and chlorine forms the compound salt, which neither ignites upon contact with water nor is it poisonous. This is an example showing that a compound has ____________ different from the properties of the individual ________ making up that compound.
PROPERTIES ELEMENTS	10. The properties of a compound will depend on the chemical combination of its elements. Some examples are as follows: a. Two parts hydrogen and one part oxygen form the compound water (H_2O). b. Two parts hydrogen and two parts oxygen form the compound hydrogen peroxide (H_2O_2). c. One part hydrogen, one part nitrogen, and three parts oxygen form the compound nitric acid (HNO_3). These three compounds have different properties because of the difference in the chemical combination of their ____________.
ELEMENTS	11. When two or more different elements are chemically combined, a compound is formed. The properties of the compound will depend on the ________ combination of its elements.
CHEMICAL	12. When the elements hydrogen, sulfur, and oxygen are properly combined chemically, sulfuric acid (H_2SO_4) is formed. A chemical combination of two or more different elements forms a ________.

COMPOUND	13. Select the definition of a compound. a. A combination of elements. b. A chemical combination of two or more different elements. c. A physical combination of two or more different elements.
b.	14. When compounds or elements are combined and no chemical action takes place, a mixture is formed. The compounds water (H_2O) and sulfuric acid (H_2SO_4), as used in a battery, do not chemically combine. Therefore, they form a ______________.
MIXTURE	15. When the elements aluminum, nickel, cobalt, and iron are combined, ALNICO is formed. ALNICO is a mixture; therefore, the elements do not lose their original characteristics. ALNICO is used to make magnets, and is a mixture composed of different ______________.
ELEMENTS	16. When the compounds salt and fresh water are mixed, the result is salt water. By distillation, they can easily be separated and once again become salt and fresh water. By this example, we can see that compounds, when mixed, ______________ (retain/lose) their original characteristics.
RETAIN	17. ALNICO is a mixture of elements, while salt water is a mixture of compounds. A mixture can be composed of ______________ or ______________.
ELEMENTS COMPOUNDS	18. A mixture is a combination of elements or compounds in which the elements or compounds do not lose their original characteristics. ALNICO and salt water can be separated and their elements or compounds will not lose their ______________ ______________________________.

ATOM

27.



Each of the above represents the smallest particle of an ______________.

ELEMENT

28. Match the definitions in column B with their proper terms in column A. Place the number before the definition in the space beside the proper term.

A		B
a. Compound	____	1. The smallest particle of an element.
b. Mixture	____	2. A chemical combination of two or more different elements.
c. Molecule	____	3. The smallest particle of a compound which has all the properties of that compound.
d. Atom -	____	4. A combination of elements or compounds in which the elements or compounds do not lose their original characteristics.

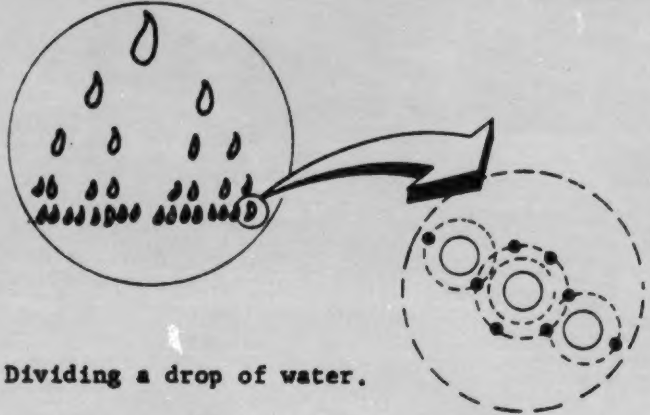
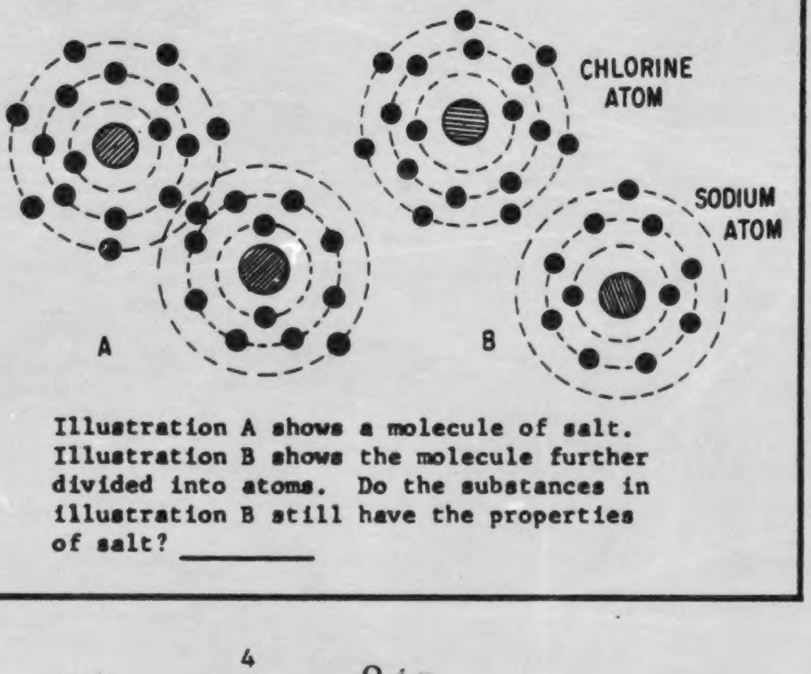
a. 2
b. 4
c. 3
d. 1

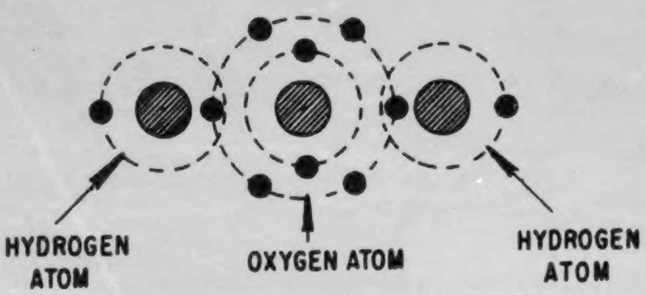
29. The smallest particle of an element is an atom. The atom cannot be seen by the usual microscopic instruments. Although they cannot be seen, we know there are many kinds of ________________.

ATOMS

30. The number of protons, neutrons, and electrons will vary with each kind of atom. The oxygen atom and the helium atom have different numbers of ______________, ________________, and ________________.

	1. Everything in the universe that has weight and occupies space is matter. Matter can be broken down into elements - substances which cannot be altered by chemical means. NO RESPONSE REQUIRED
	2. There are over 100 known elements. Most are natural; a few are man-made. Some natural elements are oxygen, gold, tin, and carbon. Hydrogen, silver, and lead are also examples of natural ______________________.
ELEMENTS	3. Matter exists either as a natural element or as a chemical combination of two or more different elements. This combination is called a compound. A compound can be divided into two or more different ___________________.
ELEMENTS	4. Some familiar examples of compounds are water, a combination of hydrogen and oxygen, and salt, a combination of sodium and chlorine. Because water and salt can be divided into different elements, they are ______________________.
COMPOUNDS	5. When compounds are chemically changed to form new compounds or when they are broken down into their original elements, the action is called chemical action. When sweet milk is chemically changed to sour milk, the action is called _________________ ______________.
CHEMICAL ACTION	6. When sulfuric acid, a compound, reacts with the compound lead peroxide in a battery, lead sulfate is formed. This action between two compounds to form a new compound is called ___________________ _______________.
CHEMICAL ACTION	7. The elements hydrogen and oxygen are gases. When properly combined chemically, these elements will form the compound water. Water is a _______________. (liquid/gas)

ORIGINAL CHARACTERISTICS	19.  Dividing a drop of water. A molecule. By taking one drop of the compound water and dividing it into smaller and smaller parts, as shown, the smallest part of water we can reduce it to is a ______________________.
MOLECULE	20. The smallest particle of a compound, which has all the properties of that compound, is a molecule. The smallest particle that the paper on which you are writing could be broken down to and still be paper is a ______________________.
MOLECULE	21. The smallest particle of a compound, which has all the properties of that compound, is a molecule.  Illustration A shows a molecule of salt. Illustration B shows the molecule further divided into atoms. Do the substances in illustration B still have the properties of salt? _________

NO	22. Select the definition of a molecule. a. The smallest particle of a compound. b. The smallest particle of a compound which has all the properties of that compound. c. The smallest particle of any substance.
b.	23.  The illustration above shows that a water molecule is made up of __________ (number) oxygen atom and __________ (number) hydrogen atoms.
ONE TWO	24. A molecule is composed of two or more atoms. If a substance is divided down to a molecule, the molecule will be made up of two or more ________.
ATOMS	25. Atoms are the basic building material of all matter. All matter is made up of _____________.
ATOMS	26. The atom is the smallest particle of an element. When an element is reduced to its smallest particle, that particle is an ____________.

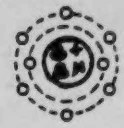
A. 7

B. 26

C. 13

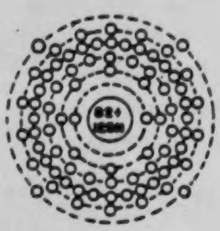
33. Lead is much heavier than oxygen. A lead atom is heavier than an oxygen atom because it contains more protons (+) and neutrons (N).
The atomic weight of an atom is determined by adding the number of protons (+) and neutrons (N) contained in the center (nucleus) of the atom.

A



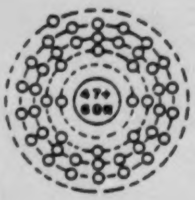
Oxygen.

B



Lead.

C



Silver.

What is the atomic weight of the above atoms?

A. _________ B. _________ C. _________

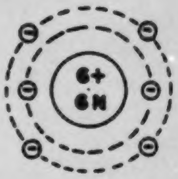
A. 16

B. 207

C. 107

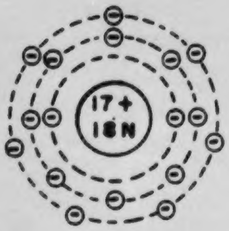
34. What are the atomic number and atomic weight of each atom illustrated below?

A



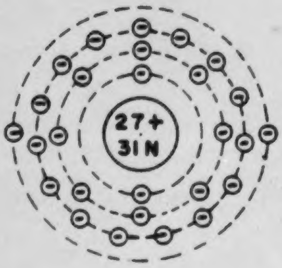
Carbon.

B



Chlorine.

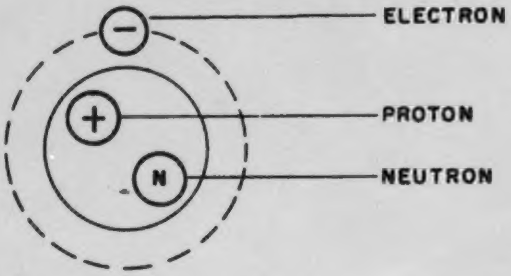
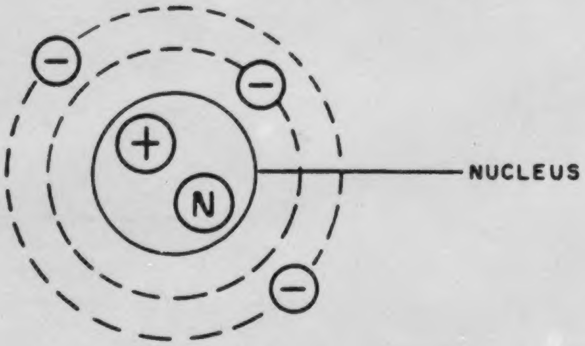
C



Cobalt.

Atomic number ____ Atomic number ____ Atomic number____
Atomic weight ____ Atomic weight ____ Atomic weight____

238

A. 6 12 B. 17 35 C. 27 58	35. How are the atomic number and atomic weight determined? a. Atomic number ____________________. b. Atomic weight ____________________ ____________________.
a. THE NUMBER OF PROTONS b. THE NUMBER OF PROTONS AND NEUTRONS	36. The atom is composed of three particles. What are they? ____________, __________, ____________. 
ELECTRONS PROTONS NEUTRONS	37.  The center of the atom is the ____________.
NUCLEUS	38. The center of the atom, which contains the protons and neutrons, is the ________________.

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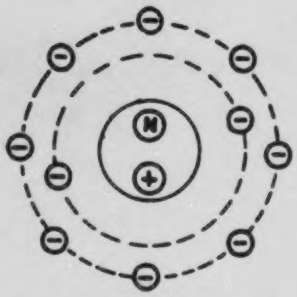
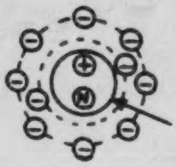
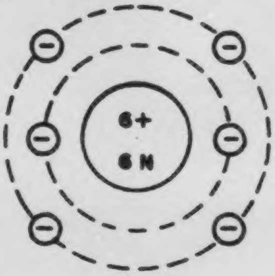
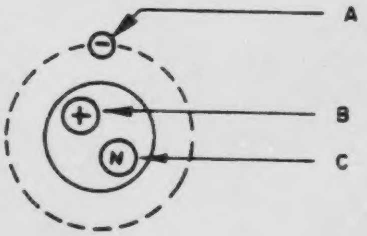
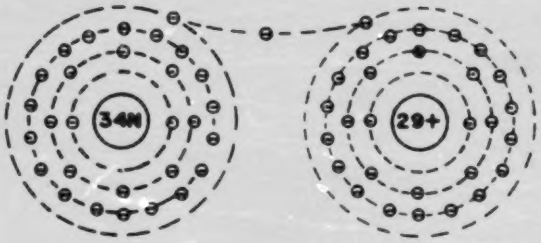
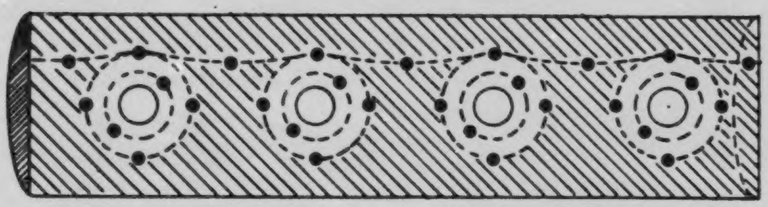
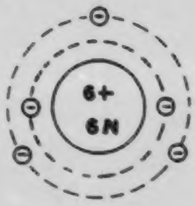
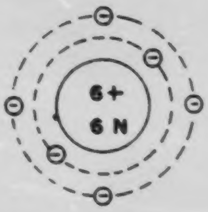
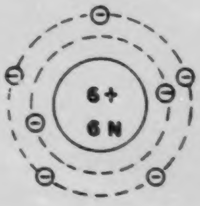
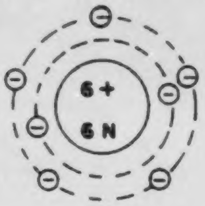
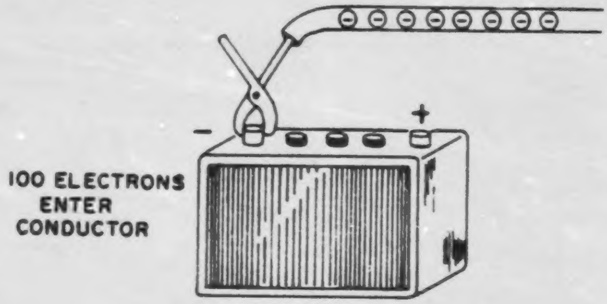
NUCLEUS	39.  Draw an arrow pointing to the nucleus of this atom.
	40. The protons of an atom have a positive charge and are identified by a plus (+) sign. A proton has a ________________ charge.
POSITIVE	41. Protons are identified by a ( ) sign.
(+)	42. The neutrons of an atom have a neutral charge (no charge) and are identified by an (N) sign. A neutron has a ________________ charge.
NEUTRAL	43. Neutrons are identified by an ( ) sign.
(N)	44. The electrons of an atom have a negative charge and are identified by a minus (-) sign. An electron has a ________________ charge.
NEGATIVE	45. Electrons are identified by a ( ) sign.

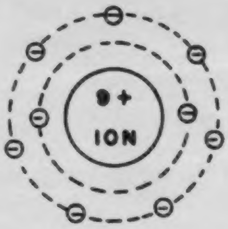
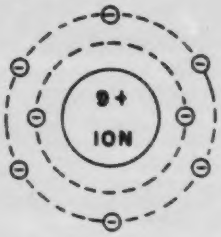
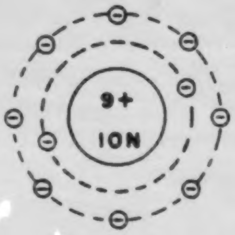
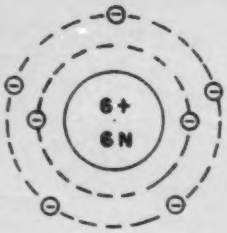
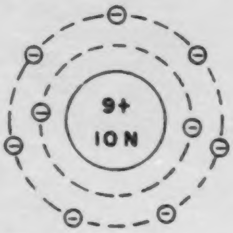
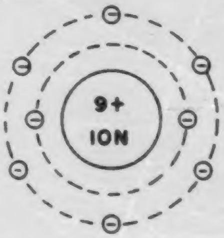
(-)	46. Electrons are in orbit about the nucleus of an atom, and they can be in different orbital paths. In the atom below, how many electrons are orbiting about the nucleus? __________ 
SIX	47. The electrons are in orbit about the ____________ of an atom.
NUCLEUS	48. Label the three particles of the atom below.  A. ______________________ B. ______________________ C. ______________________ The center of an atom is the ________________.

A. ELECTRON B. PROTON C. NEUTRON NUCLEUS	49. The nucleus of an atom has an attractive force for its electrons. The strength of this attractive force will vary with each kind of atom. Between the nucleus and the electrons of an atom, there is an ______________ __________.
ATTRACTIVE FORCE	50. The attractive force between the nucleus of the copper atom, a conductor, and its outer electrons is less than the attractive force between the nucleus of the helium atom, an insulator, and its outer electrons. Which atom, copper or helium, would more readily give up its outer electrons? ______________
COPPER	51. In the atoms of good electrical conductors, silver, copper, and gold, the outer electrons are readily freed from the attractive force of their ______________.
NUCLEUS	52. A good conductor has atoms with loosely held electrons. A copper atom has loosely held ______________.
ELECTRONS	53. Electrons that are loosely bound (held) to an atom can be moved out of orbit easily. Electrons of a gold atom can be moved out of orbit easily because they are ______________ __________.
LOOSELY BOUND	54. **FREE ELECTRON**  Copper atoms. When a loosely bound electron is removed from orbit, it is called a ________ ______________ (see illustration).

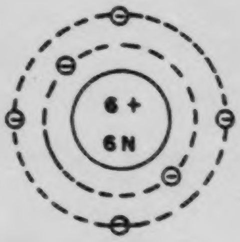
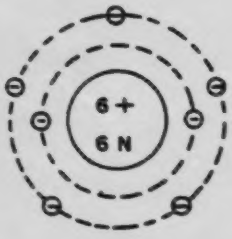
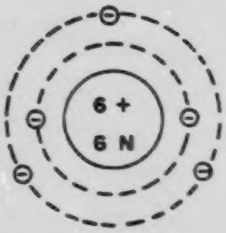
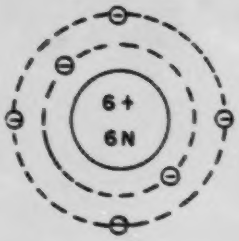
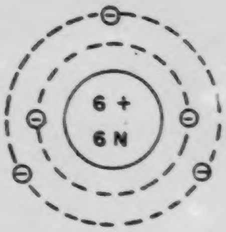
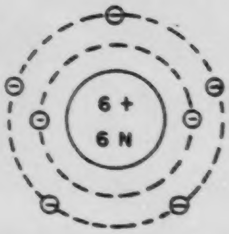
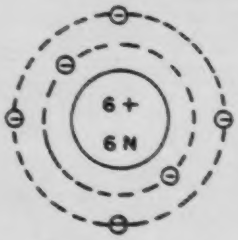
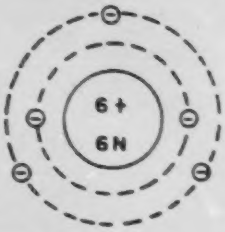
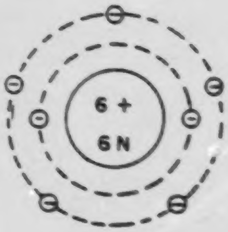
FREE ELECTRON	55. Electrons removed from their orbit about an atom are called _________ ________________.
FREE ELECTRONS	56. An insulator, such as rubber, has very few free electrons and will not conduct electricity. A good insulator contains a small number of ______ ________________.
FREE ELECTRONS	57. Materials with a small number of free electrons are good ________________.
INSULATORS	58. The controlled movement of free electrons through a conductor is electrical current flow. In comparison to an insulator, a conductor has a large number of _________ ____________________.
FREE ELECTRONS	59. Materials having a large number of free electrons are good ____________________.
CONDUCTORS	60. Electrons removed from their orbit are free electrons. How does a good conductor compare to a good insulator with respect to the number of free electrons in each? a. Conductor ____________________________. b. Insulator ____________________________.
a. HAS A LARGE NUMBER b. HAS A SMALL NUMBER	61. Some materials, carbon, germanium, and silicon, are considered semiconductors. This is because they conduct less current than metal conductors but more than insulators. Materials that conduct less current than metal conductors but more current than insulators are ___________________________.

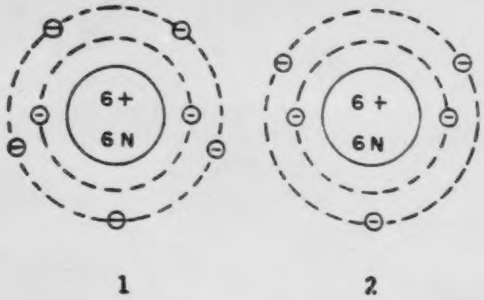
SEMICONDUCTORS	62. In a conductor, free electrons are continually moving from one atom to another. By controlling the movement of these free electrons in one general direction, electrical energy is transferred through a conductor. Electrical energy is transferred through a conductor by the movement of __________ ______________ from atom to ___________.
FREE ELECTRONS ATOM	63. Electrical energy is transferred through a conductor when free electrons are moved from ___________ to ____________.
ATOM ATOM	64.  In the illustration above, the free electrons are moving from atom to atom through the conductor in one general direction. The result of this will be a transfer of e__________________ e_____________.
ELECTRICAL ENERGY	65. How is electrical energy transferred through a conductor? __________________________________ ____
BY THE MOVEMENT OF FREE ELECTRONS FROM ATOM TO ATOM.	66. The transfer of electrical energy is possible because an atom has a tendency to stay electrically neutral, that is, to have an equal number of protons and electrons. Which atom below is electrically neutral? ________  A  B  C

B	67. The atoms of a conductor normally stay electrically neutral because of the random movement of free electrons. As an atom gains an electron, it will give off another electron in order to be electrically neutral. How many electrons must this atom give off in order to be electrically neutral? ________ 
ONE	68. An electrically neutral atom is an atom that has an equal number of __________ and ____________.
PROTONS ELECTRONS	69. An outside source such as a battery can be used to add additional electrons to a conductor. When these excess electrons are added, a chain reaction of moving electrons through the conductor is set up because the atoms tend to stay electrically _________________.
NEUTRAL	70. If an outside force adds one million electrons to one end of a conductor, then one million electrons must come out the other end of the conductor. The same number of electrons that enter a conductor must leave that conductor. How many electrons must leave the conductor below? ______ 

100	71. Select the electrically neutral atom. ______  A  B  C
A	72. An atom that has more electrons than protons has an excess of electrons. An atom with fewer electrons than protons has a deficiency of ____________________.
ELECTRONS	73. An atom that has an excess of electrons is an electrically charged atom. An atom that has a deficiency of electrons is also an ______________ charged atom.
ELECTRICALLY	74. An electrically charged atom is known as an ion. An ion has an ____________ or a ________________ of electrons.
EXCESS DEFICIENCY	75. Which of these atoms are ions? ______ ______  A  B  C

A C	76. An ion is an atom having an __________ or a ________________ of electrons.
EXCESS DEFICIENCY	77. Match the definitions in column B with their terms in column A. Place the number before the definition in the blank beside the proper term. A a. Compound ____ b. Mixture ____ c. Molecule ____ d. Atom ____ e. Nucleus ____ f. Ion ____ B 1. The smallest particle of an element. 2. A chemical combination of two or more different elements. 3. An atom having an excess or a deficiency of electrons. 4. A combination of elements or compounds in which the elements or compounds do not lose their original characteristics. 5. The center of the atom which contains the protons and neutrons. 6. The smallest particle of a compound which has all the properties of that compound.
a. 2 b. 4 c. 6 d. 1 e. 5 f. 3	78. Atoms that have more electrons than protons have a negative charge. A negatively charged atom has more ______________ than __________________.

ELECTRONS PROTONS	79. Which of the atoms below has a negative charge? ________  A  B  C
B	80. An atom that has fewer electrons than protons has a positive charge. A positively charged atom has fewer ____________ than ______________.
ELECTRONS PROTONS	81. Which of the atoms below has a positive charge? ________  A  B  C
B	82. Label the atoms below as having a positive, negative, or neutral charge.  A ________  B ________  C ________

A. NEUTRAL B. POSITIVE C. NEGATIVE	83. When a negatively charged atom is contacted by a positively charged atom, the electrons flow from the negative atom to the positive atom. When two atoms of opposite charges contact each other, the electron flow is from ______________ to _________________.
NEGATIVE POSITIVE	84. Which direction will the electrons flow between the two atoms below? ________ a. From atom 1 to atom 2. b. From atom 2 to atom 1. 
a.	85. When a negatively charged atom is contacted by a positively charged atom, electrons will flow from the ______________ atom to the _________________ atom.
NEGATIVE POSITIVE	

BASIC ELECTRICITY REVIEW

PART II

ATOMIC STRUCTURE

SELF-TEST

1. Match the definitions in column B with their terms in column A. Place the number before the definition in the blank space beside the proper term.

A

a. Compound ____

b. Mixture ____

c. Molecule ____

d. Atom ____

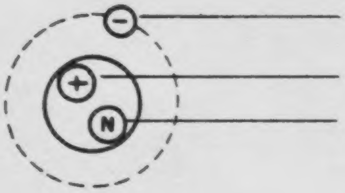
e. Nucleus ____

f. Ion ____

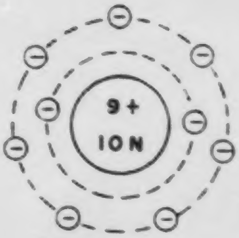
B

1. The smallest particle of an element.
2. A chemical combination of two or more different elements.
3. An atom having an excess or a deficiency of electrons.
4. A combination of elements or compounds in which the elements or compounds do not lose their original characteristics.
5. The center of an atom which contains the protons and neutrons.
6. The smallest particle of a compound which has all the properties of that compound.

2. Label the three particles of the atom below.



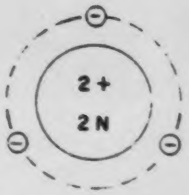
3. What are the atomic number and the atomic weight of the atom below?



Atomic number ____________

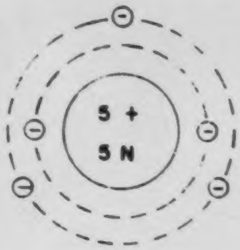
Atomic weight ____________

4. Label these atoms as having a positive, negative, or neutral charge.



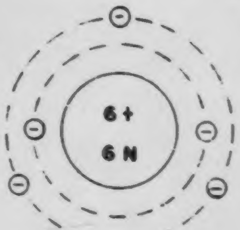
A

____



B

____



C

____

5. Electrons removed from their orbit about an atom are called ________ ________.

6. How does a good conductor compare to a good insulator with respect to the number of free electrons in each?

Conductor ________.
Insulator ________.

7. How is electrical energy transferred through a conductor?

____

8. When a negatively charged atom is contacted by a positively charged atom, electrons will flow from the ________ atom to the ________ atom.

PROGRAMMED INSTRUCTION

2-5

AIRCRAFT NOMENCLATURE

Aviation Training Division
USCG-AR&SC-Elizabeth City, N. C.

WARNING

THE MATERIAL IN THIS PAMPHLET IS FOR TRAINING ONLY. IT SHOULD NEVER BE USED IN LIEU OF OFFICIAL INSTRUCTIONS, TECHNICAL ORDERS, OR OTHER CURRENT PUBLICATIONS ISSUED BY COMPETENT AUTHORITY. ALWAYS CHECK THE LATEST DIRECTIVES AND PUBLICATIONS ON THE JOB.

INSTRUCTIONS

This booklet is called a program, and it will be easy for you to learn the subject this program covers. It will be easy because the information you are to learn is broken down into small, easily understood parts, called frames. Each frame contains information you are to learn and presents you with a question to answer. This keeps your brain active -- just like answering questions in class. After you have written your answer to a frame, you will be able to see immediately the correct answer. This lets you know whether your answer is right or wrong -- just like having an instructor tell you whether or not your answer is correct. These three things: reading, answering questions, and being shown the correct answer will ensure that learning takes place.

Even though the program is designed to make it easy for you to learn, there are certain things you must do in order for it to be successful. If you will follow the suggestions listed below, you should have no trouble learning the material in this program.

1. Read the objectives very carefully before you begin, so you will know what you are to learn.
2. Keep the answer to the frame you are working on covered with a slip of paper until you have written your answer. (The correct answer is usually found to the left of the frame following the one you are working on.)
3. After writing your answer to a frame, move the slip of paper to expose the correct answer, so you can see whether or not you are right.
4. Always follow, very carefully, any directions given in the program.
5. If there is something in the program you do not understand, ask the instructor for help.
6. When you have finished the program, read the objectives again to make sure you can do what the objectives require.
7. Take the self-test at the end of the program; this will indicate whether you have learned what you were supposed to learn.

AIRCRAFT NOMENCLATURE

OBJECTIVES

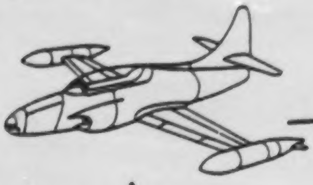
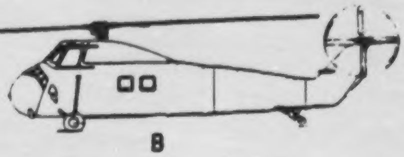
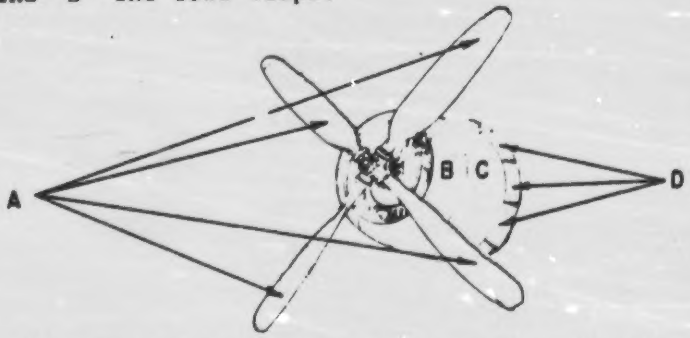
1. Given an illustration of an aircraft, label the cockpit, empennage, propeller, arresting hook, speed ring, wing, cowl flaps, and fuselage.
2. Given an illustration of an aircraft, label the aileron, rudder, elevator, trim tab, wing flap, and speed brake.
3. Given a list of statements, select those that pertain to the fixed landing gear, retractable landing gear, and nose and tail wheel assembly.
4. Given illustrations of helicopters, label them as being either single main rotor or tandem-rotor aircraft.
5. Given a list of statements, select those that pertain to the clutch, free-wheeling unit, transmission, and power plant.
6. Given an illustration of a helicopter, label the pylon, cabin, and tail cone section.
7. State where the points of origin for the fuselage and stabilizers begin, and state what unit of measurement is used in the station numbering system.

INTRODUCTION

All aircraft repairmen must know the components of their aircraft, regardless of their rate or MOS. The construction of all aircraft is basically the same. They all consist of a fuselage, some type of wing, stabilizers, and controls.

This program will give you the names and locations of all these components, and at times explain their purpose.

SUGGESTED READING TIME 64 MIN.

	1. There are two types of aircraft used in naval aviation: FIXED wing and ROTARY wing. Any aircraft that does not use a series of rotating airfoils for its wing is a FIXED-wing aircraft. Circle the letter under the fixed-wing aircraft.  A  B
A FIXED WING	2. There are three types of engines used on fixed-wing aircraft: TURBOJET, TURBOPROP, and RECIPROCATING. The illustration below shows a reciprocating radial type of engine. The letter "A" represents the propeller, "B" the speed ring, "C" the engine cowling, and "D" the cowl flaps.  The propeller is a series of rotating airfoils used to propel the aircraft. Circle the letter designating the propeller in the illustration. The speed ring is designed to direct a flow of cooling air around the cylinders of the engine. It streamlines the engine section. This eliminates turbulence which reduces drag. Circle the letter that represents the speed ring. The cowl flaps are designed to regulate the engine temperature by opening and closing. The cowl flaps are controlled by the pilot. Circle the letter that represents the cowl flaps. The engine cowling also aids in cooling the engine. It can be removed to gain access to the engine. Circle the letter that indicates the engine cowling.

A PROPELLER

B SPEED RING

D COWL FLAPS

C ENGINE COWLING

3. Match each component in column A with the statement in column B to which it pertains. Place the letter from column A beside the correct number in column B.

COLUMN A	COLUMN B
A. SPEED RING	____ 1. Designed to direct a flow of cool air around the engine cylinders
B. ENGINE COWLING	____ 2. Aid the pilot in controlling engine temperature
C. PROPELLER	____ 3. Can be removed to gain access to the engine
D. COWL FLAPS	____ 4. Series of rotating airfoils which propel the aircraft

A 1.

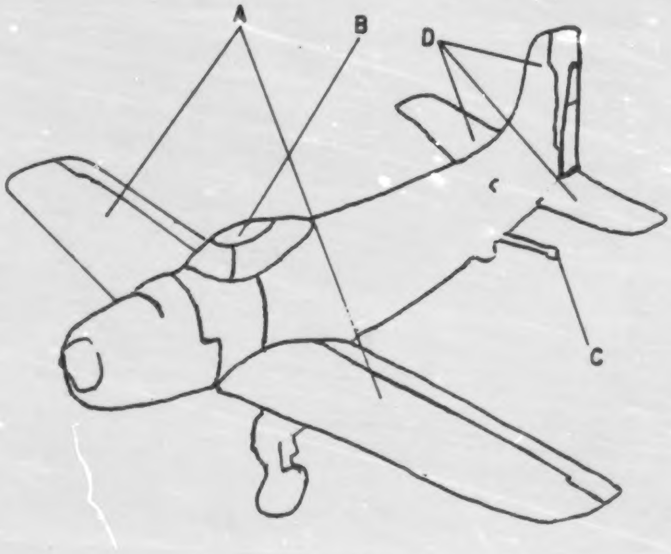
D 2.

B 3.

C 4.

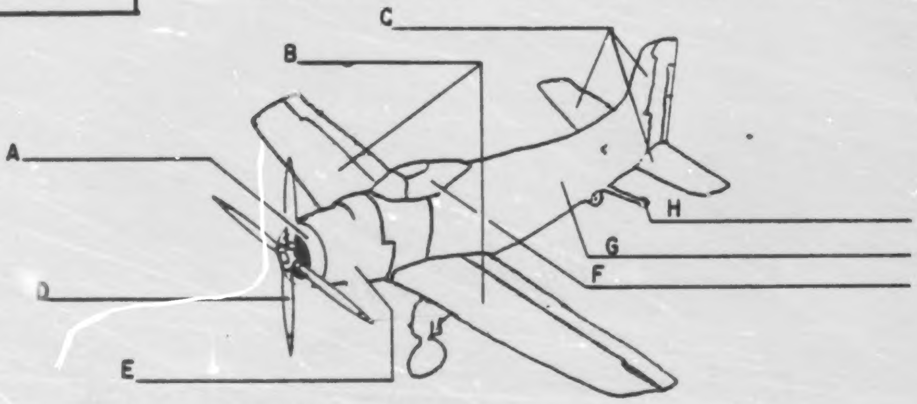
4. FUSELAGE: A French word meaning spindle-shaped. It is used to identify the section of the aircraft that normally houses, or has attached, the COCKPIT, CREW SPACE, WINGS, TAIL SECTION, FUEL TANKS, ARRESTING HOOK, and CARGO SPACE.

Study this aircraft.



Continue to the next frame.

	5. The cockpit is the portion of the aircraft that houses the pilot, the instruments, and the controls. Circle the letter that represents the cockpit (frame 4). The wing is designed to develop the major portion of the lift of the aircraft. It is normally attached to the forward section of the FUSELAGE. Circle the letter that shows the wing (frame 4). The tail section, better known as the empennage, is designed to stabilize the aircraft as the feathers stabilize the flight of an arrow. Circle the letter that points to the empennage (frame 4). The arresting hook is used to stop the aircraft when landing aboard aircraft carriers. It is normally located at the rear of the aircraft. Circle the letter that represents the arresting hook (frame 4).
B COCKPIT A WING D EMPENNAGE (TAIL SECTION) C ARRESTING HOOK	6. Circle the letter(s) beside the statement(s) that pertain to the fuselage. A. Creates the major portion of the lift of the aircraft. B. Normally has the wing and tail section attached. C. Houses the tail section and wing. D. Houses the controls, instruments, and pilot. E. Contains the arresting hook.
B AND E ARE CORRECT	7. Label the COCKPIT, EMPENNAGE, PROPELLER, ARRESTING HOOK, SPEED RING, WINGS, COWL FLAPS, and FUSELAGE.



A SPEED RING
B WINGS
C EMPENNAGE (TAIL SECTION)
D PROPELLER
E COWL FLAPS
F COCKPIT
G FUSELAGE
H ARRESTING HOOK

8. The wing shown on page five is known as the CANTILEVERED type of wing. It is easily recognized as that type of wing because it has no external bracing such as wires or struts. It is supported by spars which run from wing tip to wing tip inside the wing.

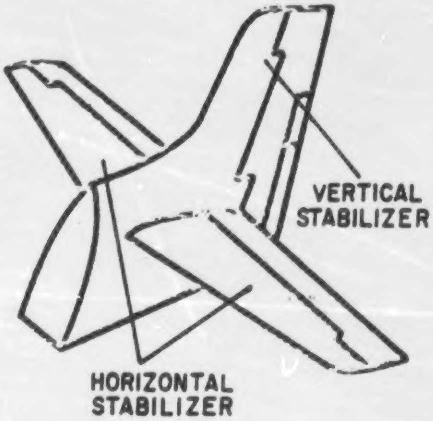
How can a cantilever wing be recognized?

ANSWER ______________________________

______________________________.

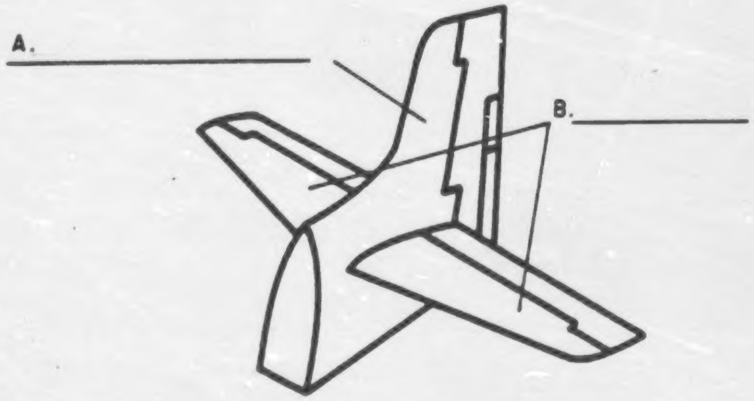
HAS NO EXTERNAL BRACING

9. When we mention the words VERTICAL and HORIZONTAL stabilizers, we are referring to the tail section, as shown in the illustration below.



NO RESPONSE REQUIRED

10. Label the stabilizers as being either horizontal or vertical in this illustration.



A. VERTICAL

B. HORIZONTAL

11. On fixed-wing aircraft, there are three control surfaces that are considered as the primary controls: AILERONS, ELEVATOR, and RUDDER. All these controls are controlled from the cockpit by the pilot.

The ailerons are located on the trailing edge of the wing near the wing tip. They are used to control the rolling motion of the aircraft.

The elevator is located on the trailing edge of the horizontal stabilizer; it controls the pitching motion of the aircraft.

The rudder is located on the trailing edge of the vertical stabilizer; it controls the yawing motion of the aircraft.

Match the components in column A with the statements in column B.

COLUMN A		COLUMN B
1. ELEVATOR	____	A. Located on trailing edge of vertical stabilizer
2. AILERONS	____	B. Controls pitching motion of the aircraft
	____	C. Controls yawing motion of the aircraft
3. RUDDER	____	D. Located on the trailing edge of the wing
	____	E. Located on the trailing edge of the horizontal stabilizer
	____	F. Controls rolling motion of the A/C

3 A.

1 B.

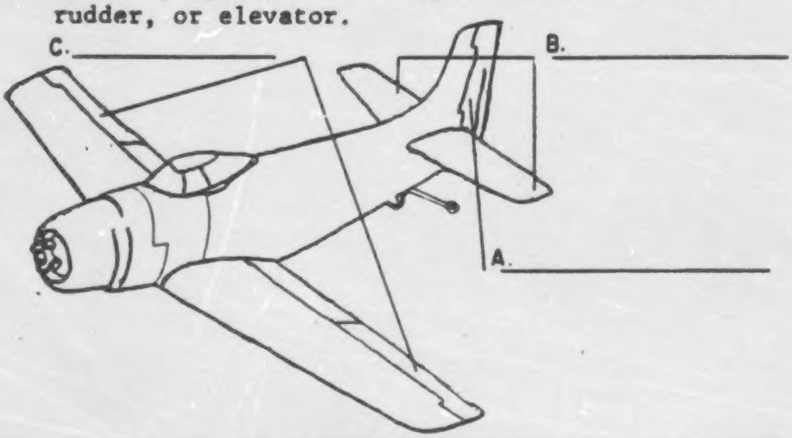
3 C.

2 D.

1 E.

2 F.

12. Label A, B, and C as being either ailerons, rudder, or elevator.



A. RUDDER

B. ELEVATOR

C. AILERONS

13. Located on the trailing edge of the primary controls are small secondary controls known as TRIM TABS. The purpose of these tabs is to trim out any unbalanced condition that may exist during flight.

What is the name of the controls that trim out any unbalanced condition during flight?

ANSWER ______________________________.

There are two types of these controls. Some aircraft incorporate both. The fixed tab can only be adjusted on the ground, whereas the movable tab can be adjusted by the pilot from the cockpit during flight.

Which tab cannot be adjusted during flight?

ANSWER ______________________________.

Another type of tab which is located on the trailing edge of the primary controls is the SPRING TAB (also called balance or servo tab). It aids the pilot in moving the primary controls at high speeds.

Which tab aids the pilot in maneuvering the aircraft at high speeds?

ANSWER ______________________________.

TRIM TABS

FIXED TAB

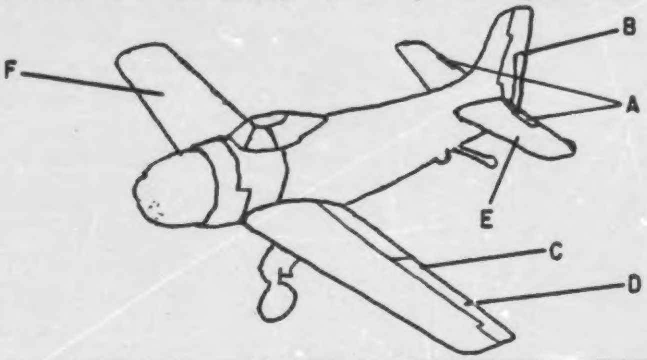
SPRING TAB

14. Match the components in column A with the statement(s) in column B. There can be more than one answer per statement.

COLUMN A		COLUMN B
A. FIXED TAB	____	1. Aids the pilot in maneuvering the aircraft at high speeds
	____	2. Located on the trailing edge of the primary controls
	____	3. Can only be adjusted on the ground
B. SPRING TAB	____	4. Trims out any unbalanced condition
C. MOVABLE TAB	____	5. Controlled by the pilot from the cockpit

B 1.
A,B,C 2.
A 3.
A & C 4.
C 5.

15. Circle the letter(s) that represent(s) TRIM TABS.



A, B, C

16. Associated with the primary and secondary controls are the AUXILIARY controls. Those most commonly found on an aircraft are the WING FLAPS, WING SPOILERS, SPEED BRAKES, and SLATS.

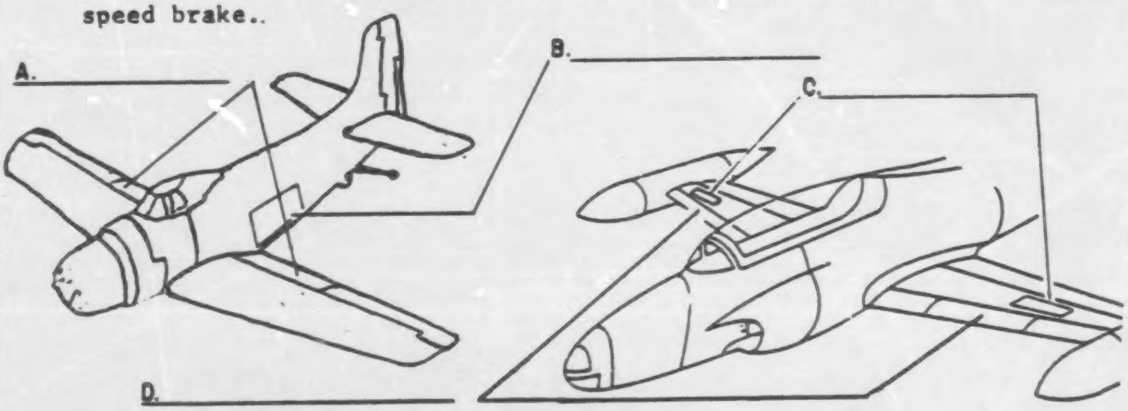
The WING FLAPS are movable controls attached to the rear of the wing just inboard of the ailerons. They serve a twofold purpose: increase lift for shorter take-offs and reduce speed for landings. They are operated by an independent control from the cockpit.

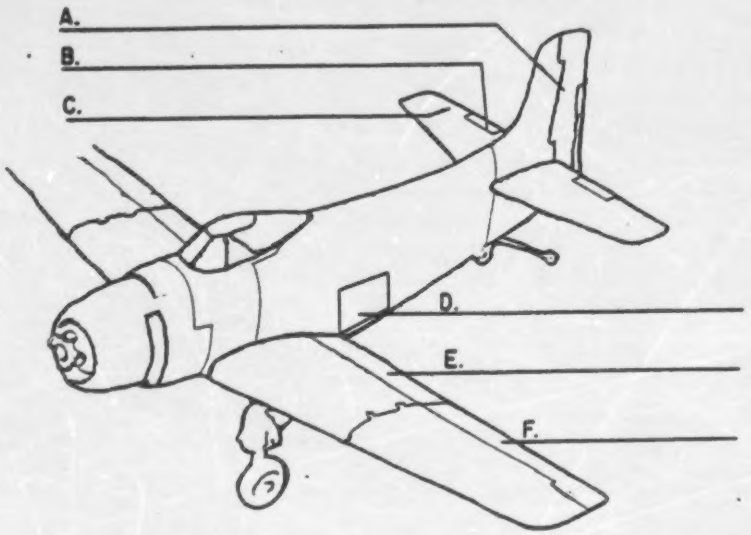
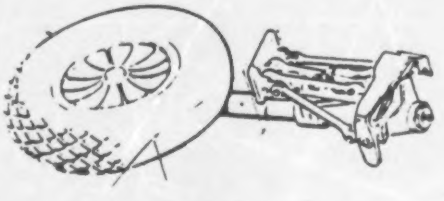
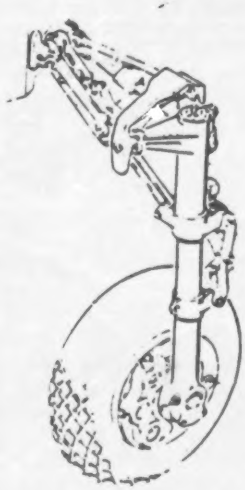
WING SPOILERS are located on top of the wing just in front of the ailerons. When either of the ailerons is raised, the spoiler in front of the raised aileron will also rise in relation to the rise of that aileron. This will cause the lift of that wing to decrease.

SPEED BRAKES (dive brakes) are usually attached to the fuselage. They are used to reduce the speed of the aircraft during dives and high-speed maneuvers. They are operated by an independent control from the cockpit.

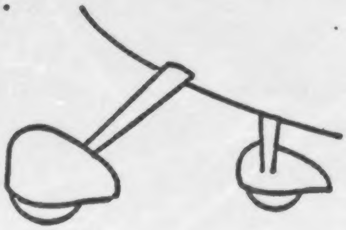
SLATS are located on the leading edge of the wing. When closed, they form the leading edge of the wing. When open, air flows through the slats and smooths out the airflow over the top surface of the wing.

In the following illustrations, label the flaps, spoilers, slats, and speed brake.

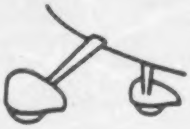


A. FLAPS B. SPEED BRAKE C. SPOILERS D. SLATS	17. Label the components in the illustration below as being either AILERON, RUDDER, ELEVATOR, TRIM TAB, WING FLAP, or SPEED BRAKE. 
A. RUDDER B. TRIM TAB C. ELEVATOR D. SPEED BRAKE E. FLAP F. AILERON	18. The MAIN LANDING GEAR is the structure that supports the major weight of the aircraft while it is on the ground. It normally contains the brakes, and it also has a shock strut to protect the structure of the aircraft during landings. There are several types of gear used. The commonest is shown in the illustrations below.  GEAR RETRACTED  GEAR EXTENDED This is a typical RETRACTABLE landing gear; it is retracted into the fuselage or wing to reduce drag.

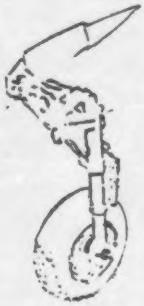
19. This is a typical FIXED landing gear; this type is attached rigidly to the aircraft and cannot be retracted.



20. Label the following illustrations as being either FIXED or RETRACTABLE.



A ______________



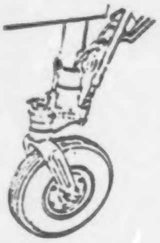
B ______________

A. FIXED

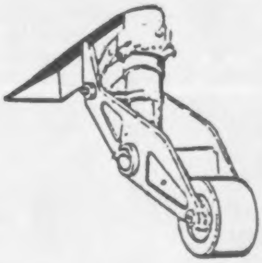
B. RETRACTABLE

21. The NOSE or TAIL wheel aids in supporting the aircraft. It has a swivel feature built into the strut so the aircraft can be turned while it is being taxied. The nose or tail wheel can either be the FIXED or RETRACTABLE type. The tail wheel has a locking feature which locks it fore and aft for landings.

Below are illustrations of typical nose and tail wheel assemblies.



NOSE WHEEL ASSEMBLY



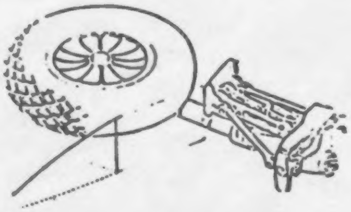
TAIL WHEEL ASSEMBLY

22. Place the letter of the component from column A in the blank next to the number of the statement that most correctly describes that component in column B. There can be more than one answer for each statement.

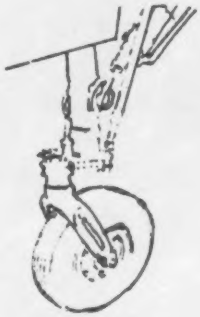
COLUMN A		COLUMN B
A. NOSE or TAIL WHEEL ASSEMBLY	____	1. Housed in the fuselage or wing while in flight to reduce drag
B. RETRACTABLE GEAR	____	2. Allows turning of the aircraft while taxiing
C. FIXED GEAR	____	3. Supports the major portion of the weight of the aircraft while it is on the ground
D. MAIN LANDING GEAR	____	4. Attached rigidly to the fuselage

B (A) 1.
A 2.
D 3.
C 4.

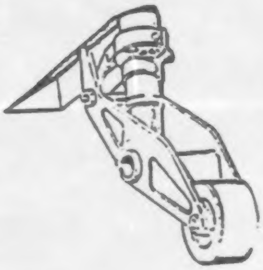
23. Label the following types of landing gear as being either NOSE, FIXED, TAIL, or RETRACTABLE.



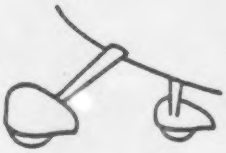
A ____________________



B ____________________



C ____________________



D ____________________

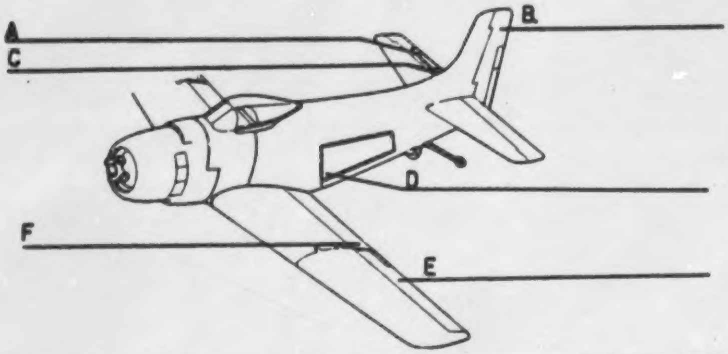
A. RETRACTABLE

B. NOSE

C. TAIL

D. FIXED

24. Label the components in the following illustration as being either RUDDER, TRIM TAB, AILERON, ELEVATOR, WING FLAP, or SPEED BRAKE.



A. TRIM TAB

B. RUDDER

C. ELEVATOR

D. SPEED BRAKE

E. AILERON

F. WING FLAP

25. Match the components in column A with the statements in column B.

COLUMN A		COLUMN B
A. RETRACTABLE GEAR	____	1. Housed in the fuselage or wing during flight to reduce drag
B. FIXED GEAR	____	2. Allows turning of the aircraft while taxiing
C. NOSE or TAIL WHEEL ASSEMBLY	____	3. Supports the major portion of the weight of the aircraft while it is on the ground
D. MAIN LANDING GEAR	____	4. Attached rigidly to the fuselage

A (C) 1.

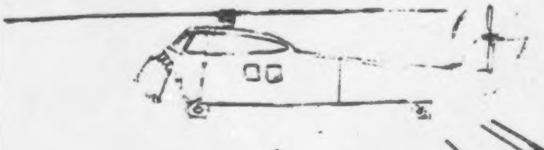
C 2.

D 3.

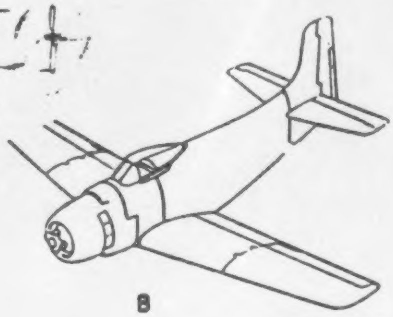
B 4.

26. Any aircraft that uses a series of rotating airfoils for its wings is a rotary-wing aircraft (helicopter).

Circle the letter under the helicopter.



A



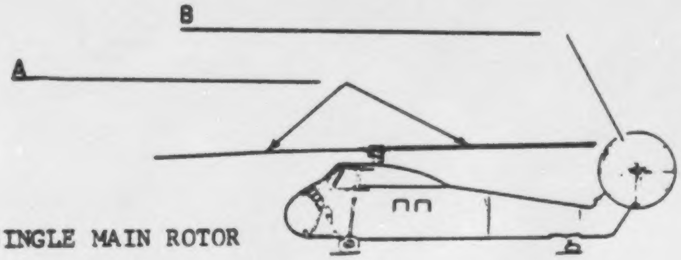
B

A

27. A rotary wing is an assembly of airfoils attached to a hub or shaft, and is called a rotor. Helicopters are classed by the number and placement of these rotors, **the two commonest being SINGLE MAIN and TANDEM rotors.**

The SINGLE main rotor, as its name implies, supports the entire weight of the aircraft. In addition, it has a tail rotor to counteract the torque developed by the main rotor and control directional heading.

Label the tail rotor and the main rotor.



SINGLE MAIN ROTOR

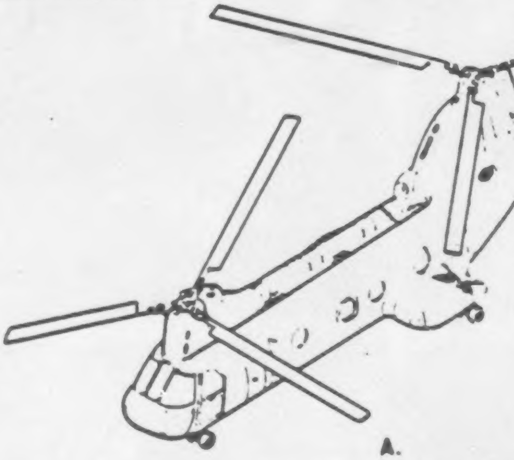
A. MAIN ROTOR

B. TAIL ROTOR

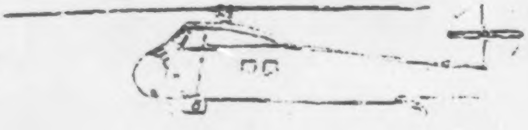
28. A helicopter with one rotor placed directly behind the front rotor is a TANDEM-rotor aircraft. By having this extra rotor, the necessity for a tail rotor is eliminated, since the rear rotor counteracts the torque developed by the front rotor and also controls directional heading.

Both of these rotors share the total weight of the aircraft.

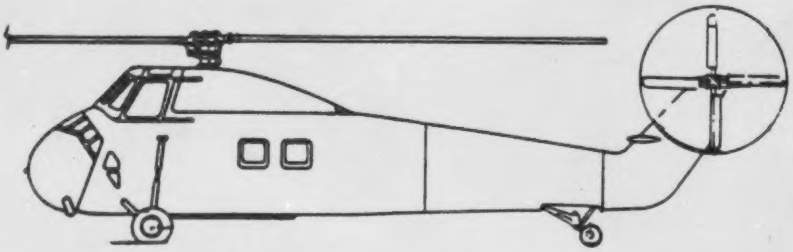
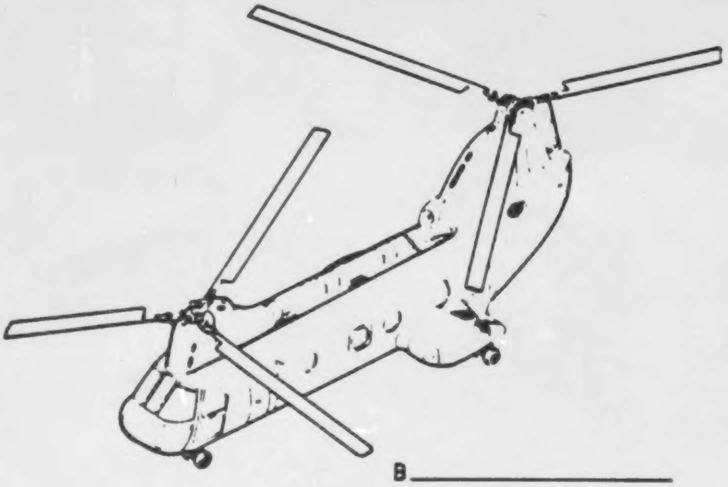
Circle the letter under the TANDEM-rotor aircraft.



A.



B.

A. TANDEM-ROTOR AIRCRAFT	**29. Label the helicopters below as being either SINGLE MAIN rotor or TANDEM-rotor type of helicopter.**  A.____________________  B____________________
A. SINGLE MAIN ROTOR AIRCRAFT B. TANDEM-ROTOR AIRCRAFT	30. Basically, there are three types of helicopters used in naval aviation: TRANSPORTS--used to carry troops, cargo, or patients. UTILITY--similar to the transport, but used to a lesser degree. Also used for air-sea rescue operations. ANTISUBMARINE--used for detection and destruction of submarines. All the above have a hoist, which enables any or all of them to perform rescue operations. What do these helicopters have that makes it possible for them to make rescue operations? ANSWER ______________________________.

HOIST

31. The power plants are either reciprocating or gas turbine types of engines. In order to reduce the engine RPM to a usable rotor RPM, a unit (component), known as the TRANSMISSION, is employed.

To operate the power plant without rotating the rotors, a CLUTCH is used.

If the power plant fails to function while in flight, a component, known as the FREE-WHEELING unit, is brought into use. This allows the pilot to make an emergency landing.

Match the components in column A with the statement(s) in column B.

COLUMN A	COLUMN B
A. FREE-WHEELING UNIT	____ 1. Enables the pilot to start the engine without engaging the rotor(s)
B. CLUTCH	____ 2. Reduces power plant RPM to a usable rotor RPM
C. POWER PLANT	____ 3. Enables the pilot to make an emergency landing without engine power
D. TRANSMISSION	____ 4. Can be either reciprocating or gas turbine

B 1.
D 2.
A 3.
C 4.

32. Match the components in column A with the statements in column B.

COLUMN A	COLUMN B
A. CLUTCH	____ 1. Reduces power plant RPM to a usable rotor RPM
B. FREE-WHEELING UNIT	____ 2. Enables pilot to make an emergency landing without engine power
C. TRANSMISSION	____ 3. Can be either reciprocating or gas turbine
D. POWER PLANT	____ 4. Enables the pilot to start the engine without engaging the rotor(s)

C 1.

B 2.

D 3.

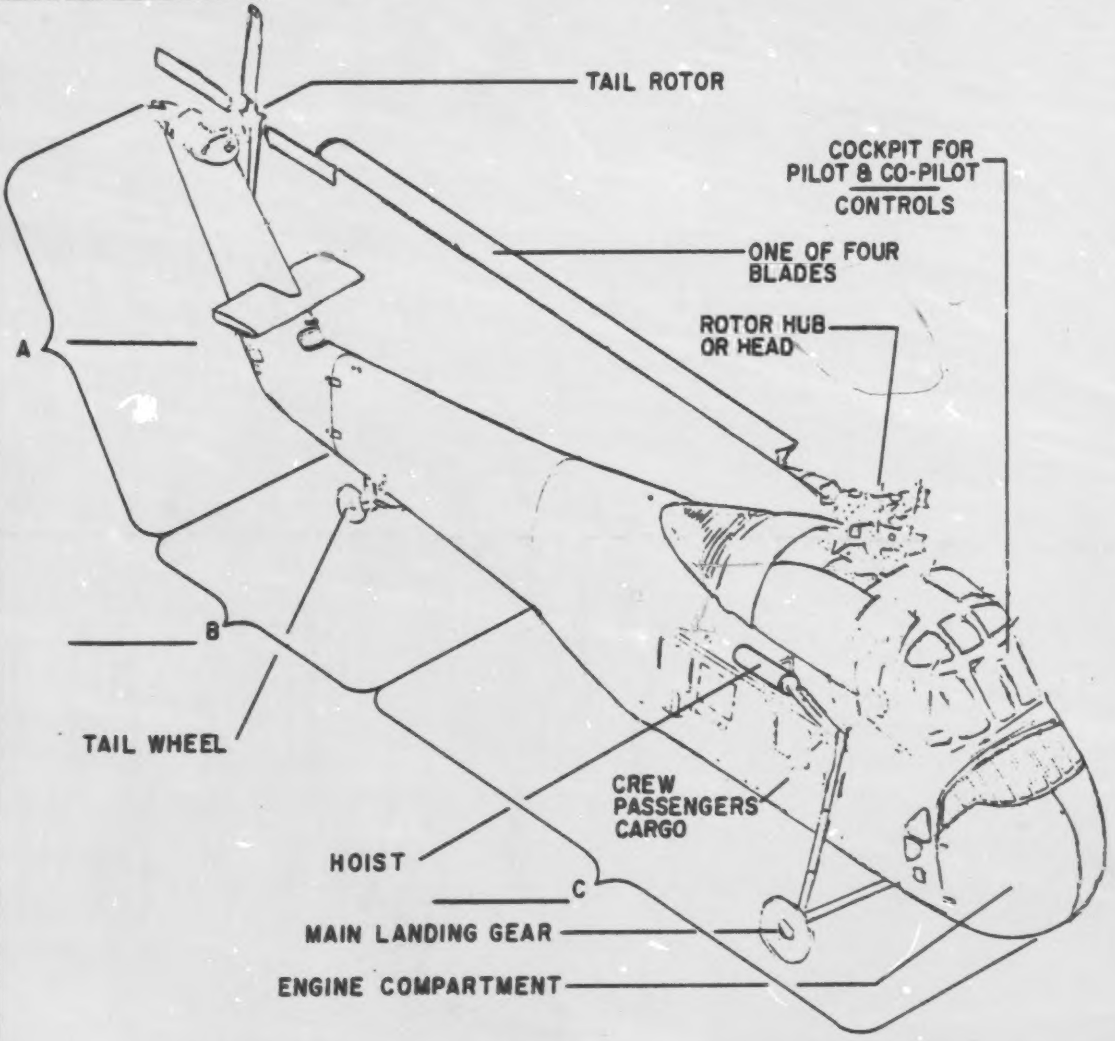
A 4.

33. The CABIN is the section of the fuselage that houses the pilot, copilot, crew, passengers, and/or cargo. It also contains the engine, main or forward rotor, main landing gear, hoist, and the controls that are used to control the aircraft.

The TAIL CONE is the section that is attached to the rear of the CABIN section. It contains the tail wheel and also supports the pylon section.

The PYLON is attached to the rear of the TAIL CONE section and contains the tail rotor.

In the illustration below, label A, B, and C as being either CABIN, PYLON, or TAIL CONE section.


TAIL ROTOR
COCKPIT FOR PILOT & CO-PILOT
CONTROLS
ONE OF FOUR BLADES
ROTOR HUB OR HEAD
A
B
TAIL WHEEL
CREW PASSENGERS CARGO
HOIST
C
MAIN LANDING GEAR
ENGINE COMPARTMENT

A-PYLON

B-TAIL CONE

C-CABIN

34. There are three types of controls used in controlling a helicopter. They are similar to the controls on a fixed-wing aircraft.

COLLECTIVE PITCH control: It is located to the left of the pilot; it is used to raise or lower the aircraft.

CYCLIC PITCH control: It is located between the legs of the pilot. It is used to move the aircraft forward, backward, or sideways.

TAIL ROTOR control: Controls the directional heading of the aircraft. Operated by a set of foot pedals located in front of the pilot.

Match the control components in column A with the statements in column B which describe these controls.

COLUMN A	COLUMN B
A. CYCLIC PITCH CONTROL	____ 1. Allows aircraft to move backwards
	____ 2. Allows aircraft to change directional heading
B. TAIL ROTOR CONTROL	____ 3. Allows aircraft to move forward
	____ 4. Allows aircraft to descend
	____ 5. Allows aircraft to move to the side
C. COLLECTIVE PITCH CONTROL	____ 6. Allows aircraft to climb

A 1.

B 2.

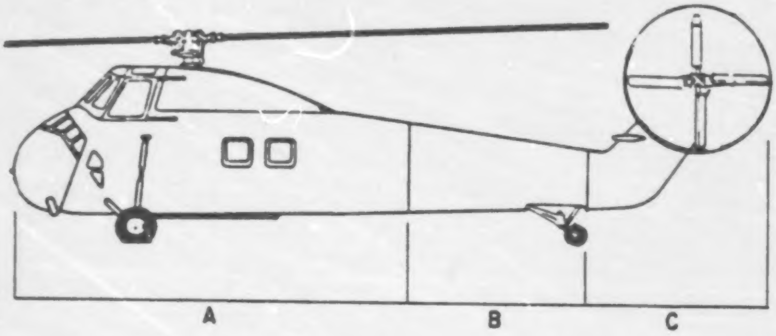
A 3.

C 4.

A 5.

C 6.

35. Label A, B, and C in the illustration below as being either TAIL CONE, PYLON, or CABIN section. section.



A. CABIN

B. TAIL CONE

C. PYLON

36. AIRCRAFT STATION NUMBERING SYSTEMS

The station numbering system is used in two ways:

1. It enables the "mech" to locate an exact area anywhere on the aircraft.
2. It is used for figuring the weight and balance of the aircraft.

FUSELAGE: The POINT OF ORIGIN starts at or near the nose of the fuselage. The POINT OF ORIGIN is always 0 (ZERO). The stations progress aft along the length of the fuselage in inches. Each station is identified by the exact amount of inches it is from the POINT OF ORIGIN, 0.

WING, VERTICAL, and HORIZONTAL STABILIZERS: The POINT OF ORIGIN for these starts at 0 at the center line of the fuselage and progresses out to the wing or stabilizer tips.

Where does the point of origin, 0 , start for the stations of the fuselage?

A. ANSWER ______________________________

____

Where does the point of origin start for the wing and stabilizers?

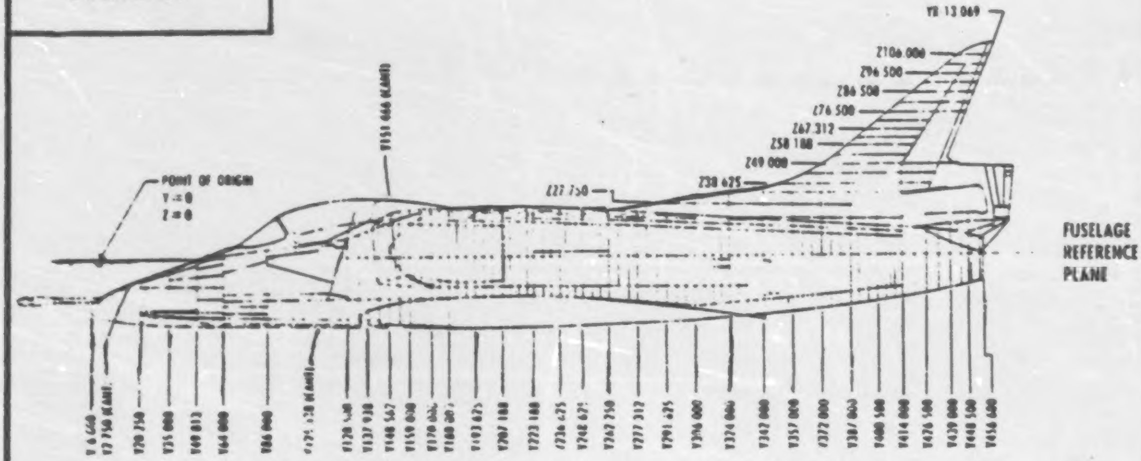
B. ANSWER ______________________________

____

A. AT OR NEAR THE NOSE

B. CENTER LINE OF THE FUSELAGE

37. The following illustration shows a typical aircraft station numbering system for the fuselage and vertical stabilizer.


YR 13.069
Z106.000
Z96.500
Z86.500
Z76.500
Z67.312
Z58.188
Z49.000
Z38.625
Z27.750
Y151.666 (FRAME)
POINT OF ORIGIN
Y = 0
Z = 0
FUSELAGE
REFERENCE
PLANE
Y-6.000
Y2.750 (FRAME)
Y20.750
Y35.000
Y49.812
Y64.000
Y86.000
Y125.128 (FRAME)
Y128.500
Y137.938
Y148.562
Y159.000
Y170.000
Y180.281
Y193.625
Y207.188
Y223.188
Y236.625
Y248.625
Y267.250
Y277.312
Y291.625
Y306.000
Y324.000
Y342.000
Y357.000
Y372.000
Y387.000
Y400.500
Y414.000
Y426.500
Y439.000
Y448.500
Y456.000

Remember, we said the stations are measured in inches. Notice the number -6.000 at the nose of the aircraft. The minus sign means the number is forward of the point of origin. The six means the point of the nose is six inches from the point of origin.

How many inches is the point of the nose from the point of origin?

Answer ________________________________.

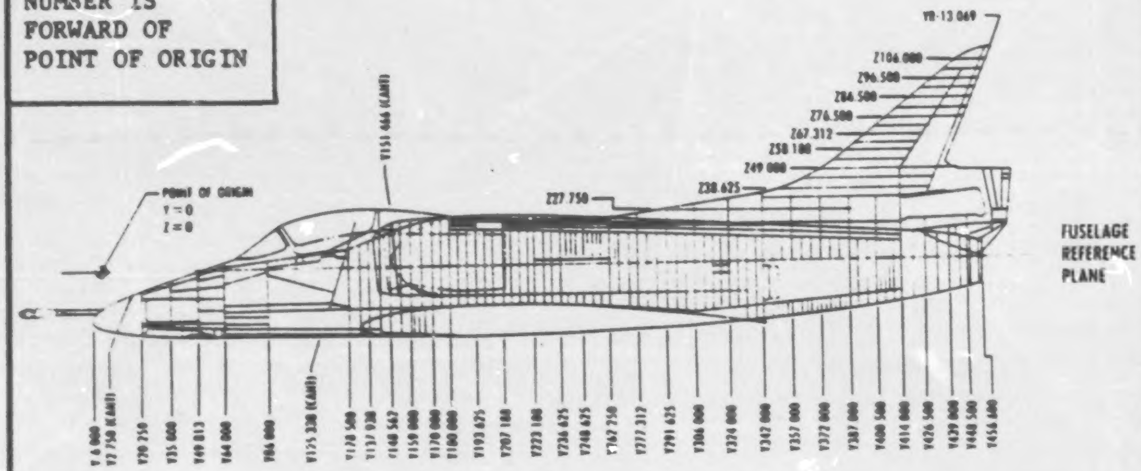
What does the minus sign mean?

Answer ________________________________.

SIX INCHES

NUMBER IS FORWARD OF POINT OF ORIGIN

38.


YR-13.069
Z106.000
Z96.500
Z84.500
Z76.500
Z67.312
Z58.188
Z49.000
Z38.625
Z27.750
Y151 466 (KANT)
POINT OF ORIGIN
Y = 0
Z = 0
FUSELAGE REFERENCE PLANE
Y 6.000
Y2 750 (KANT)
Y20 250
Y35 000
Y49 813
Y64 000
Y84 000
Y125 338 (KANT)
Y128 500
Y137 928
Y148 567
Y159 000
Y170 000
Y180 000
Y193 625
Y207 188
Y223 188
Y236 625
Y248 625
Y262 250
Y277 312
Y291 625
Y306 000
Y324 000
Y342 000
Y357 000
Y372 000
Y387 000
Y400 500
Y414 000
Y426 500
Y439 000
Y448 500
Y456 600

Look at station number 456.600 . Since there is no minus sign in front of the four, we assume station number 456.600 is aft of the POINT OF ORIGIN.

How many inches is station number 456.600 from the point of origin?

ANSWER ______________________________.

456 and 6/10 INCHES

39. At what point of the fuselage is the point of origin located?

ANSWER ______________________________.

AT OR NEAR THE NOSE

40. What do the stabilizers and wing use as the reference point for the point of origin?

ANSWER ______________________________.

CENTER LINE OF THE FUSELAGE	41. If station number 86.000 on the fuselage had no mark to indicate that it was station 86.000, how could you locate it? ANSWER ______________________________ ______________________________.
MEASURE AFT 86 INCHES FROM THE POINT OF ORIGIN FOR THE FUSELAGE	42. State where the points of origin for the fuselage and stabilizers begin, and what unit of measurement is used in the station numbering system. A. For fuselage--______________________ ______________________________. B. For stabilizers--____________________ ______________________________. C. Unit of measurement--________________.
A. AT OR NEAR THE NOSE OF THE AIRCRAFT B. CENTER LINE OF THE FUSELAGE C. INCHES	You have completed the program on Aircraft Nomenclature. Go back and review the objectives to see if you can do what they require, then do the self-test.

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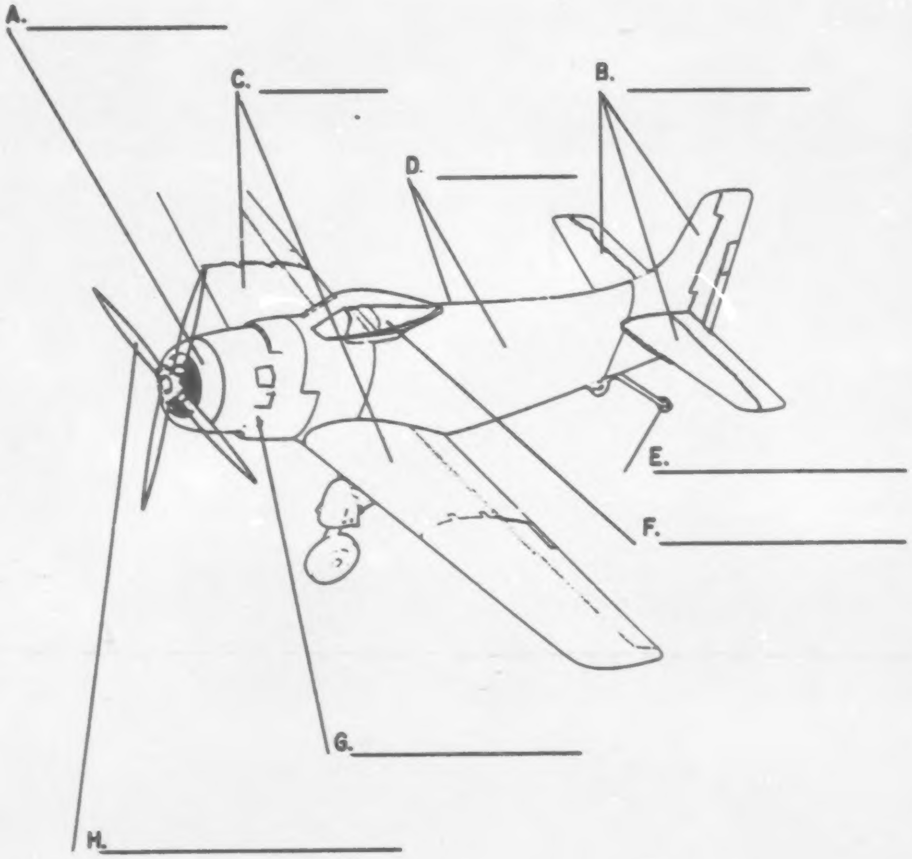
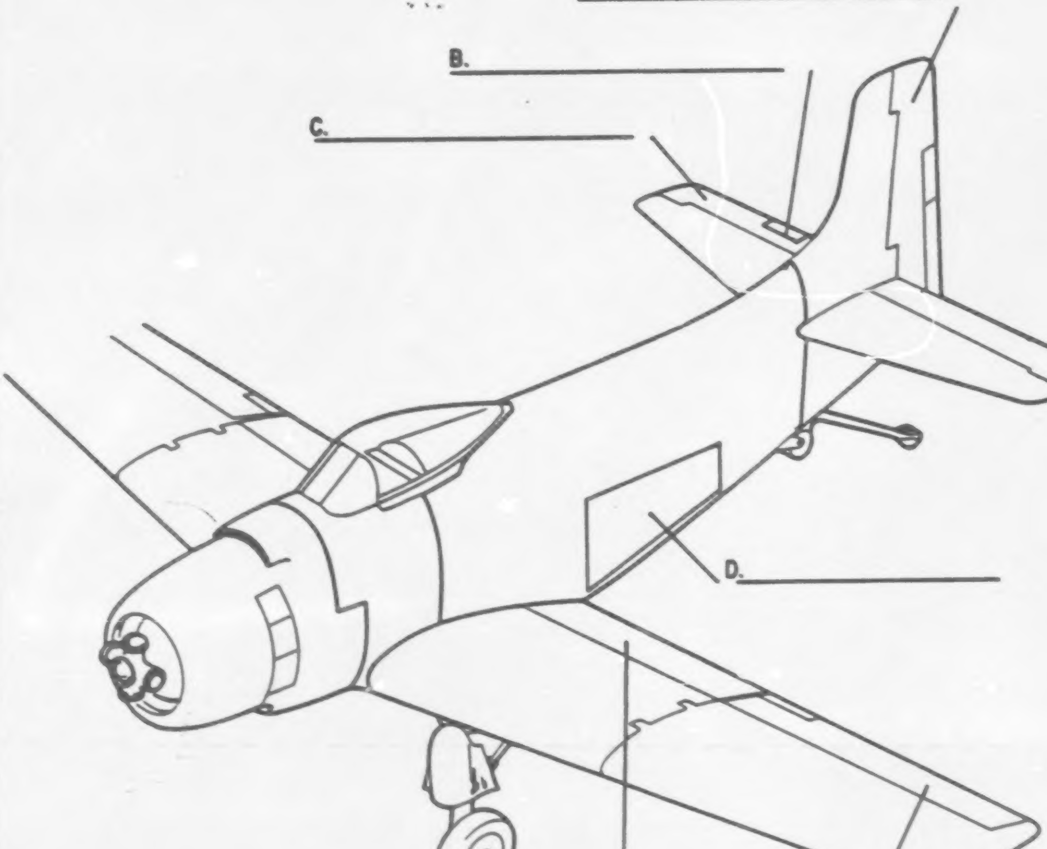
AIRCRAFT NOMENCLATURE
SELF-TEST

1. Label the areas in the illustration below as being either COCKPIT, EMPENNAGE, PROPELLER, ARRESTING HOOK, SPEED RING, COWL FLAPS, FUSELAGE, or WING.



2. Label the components in the illustration below as being either AILERON, RUDDER, ELEVATOR, TRIM TAB, WING FLAP, or SPEED BRAKE.



A. ____________________

B. ____________________

C. ____________________

D. ____________________

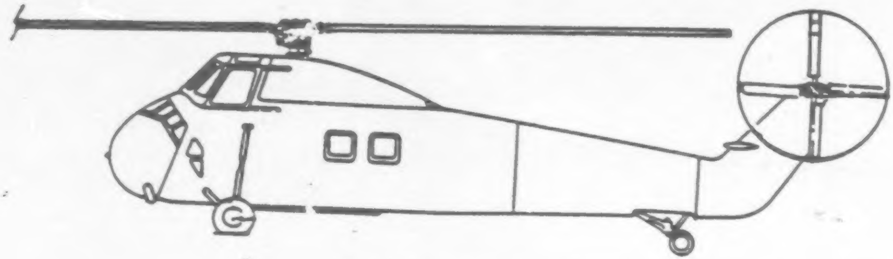
E. ____________________

F. ____________________

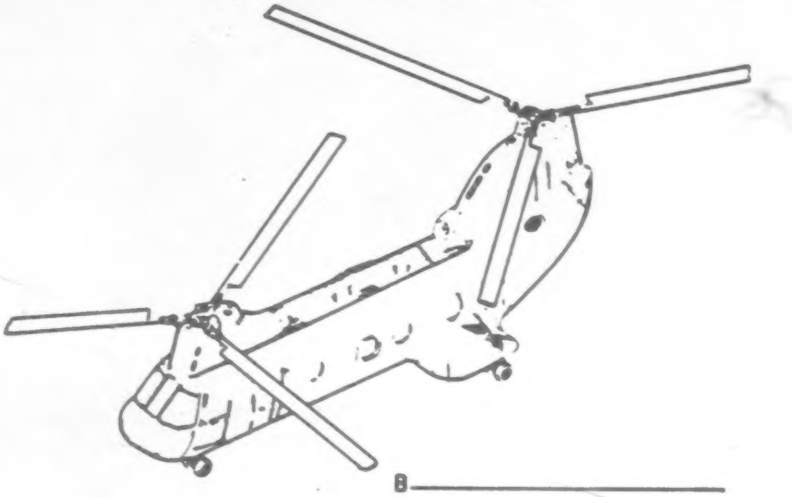
3. Match each component in column A with the statement in column B that correctly identifies that component.

COLUMN A	COLUMN B
A. RETRACTABLE GEAR	_____ 1. Housed in the fuselage while in flight to reduce drag
B. FIXED GEAR	_____ 2. Allows turning of the aircraft while taxiing
C. NOSE or TAIL WHEEL ASSEMBLY	_____ 3. Supports the major portion of the weight of the aircraft while it is on the ground
D. MAIN LANDING GEAR	_____ 4. Attached rigidly to the fuselage

4. **Label the illustrations below as being either SINGLE MAIN rotor or TANDEM-rotor aircraft.**



A.____________________

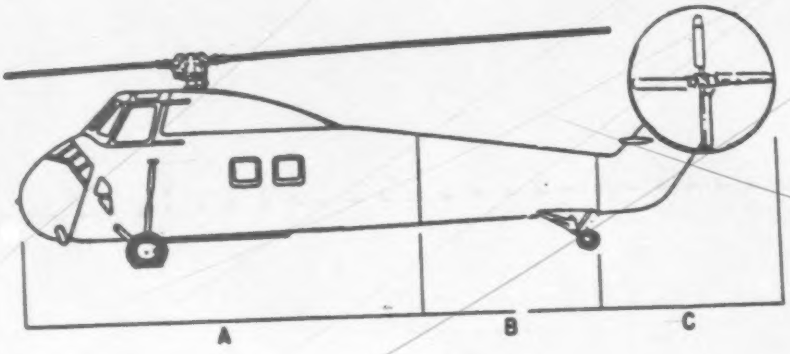


B____________________

5. Place the letter found beside each component in column A in the blank next to the number of the statement in column B which correctly identifies that component.

COLUMN A	COLUMN B
A. CLUTCH	____ 1. Reduces power plant RPM to a usable rotor RPM
B. FREE-WHEELING UNIT	____ 2. Enables the pilot to make an emergency landing without engine power
C. TRANSMISSION	____ 3. Can be either reciprocating or gas turbine
D. POWER PLANT	____ 4. Enables the pilot to start the engine without rotating the rotor(s)

6. Label the PYLON, TAIL CONE, and CABIN sections.



7. State where the POINTS of ORIGIN for the FUSELAGE and STABILIZERS begin, and state what unit of measurement is used in the station numbering system.

A. For fuselage ______________________________

____.

B. For stabilizers ______________________________

____.

C. Unit of measurement ____________________________.

PROGRAMMED INSTRUCTION

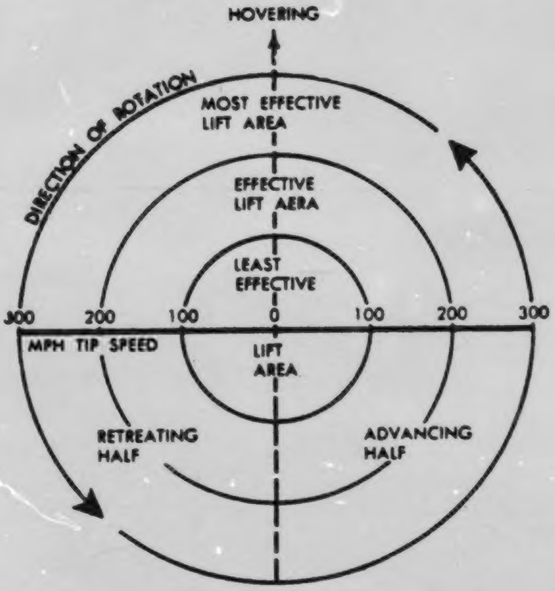
2-5

HELO AERODYNAMICS
PART II

Aviation Training Division
USCG-AR&SC-Elizabeth City, N. C.

PART II

1. Remember, back in part I of this program, we talked about the effect which speed has on lift. Let's assume that the helicopter is hovering at zero airspeed. Now, take a look at the flow of air across the rotor disc illustrated below.


HOVERING
DIRECTION OF ROTATION
MOST EFFECTIVE LIFT AREA
EFFECTIVE LIFT AERA
LEAST EFFECTIVE
LIFT AREA
300
200
100
0
100
200
300
MPH TIP SPEED
RETREATING HALF
ADVANCING HALF

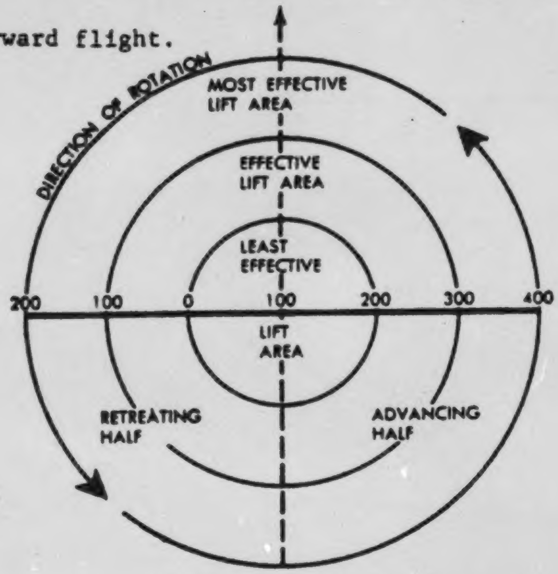
Zero Airspeed—Symmetry

You will notice that the tip speed is the same on both the left-hand side and the right-hand side of the disc.

This would tell us that lift is

________________ on both sides of the disc.
(equal/unequal)

2. Look at the illustration in this frame showing forward flight.


DIRECTION OF ROTATION
MOST EFFECTIVE LIFT AREA
EFFECTIVE LIFT AREA
LEAST EFFECTIVE
LIFT AREA
200
100
0
100
200
300
400
RETREATING HALF
ADVANCING HALF

Forward Speed—Dissymmetry

We have a forward speed of 100 m.p.h. Where we had a tip speed of 300 m.p.h. in a hover, we now have to add 100 m.p.h. to the tip speed of the advancing blade (the blade that is going in the direction of flight).

Tip speed in hover	300 m.p.h.
Forward speed of A/C	+100 m.p.h.
Advancing blade	400 m.p.h. tip speed

At the same time, 100 m.p.h. must be subtracted from the speed of the retreating blade (the blade moving opposite the direction of flight).

Tip speed in hover	300 m.p.h.
Forward speed of A/C	-100 m.p.h.
Retreating blade	200 m.p.h. tip speed

Which would have more lift, the advancing or retreating blade?

____

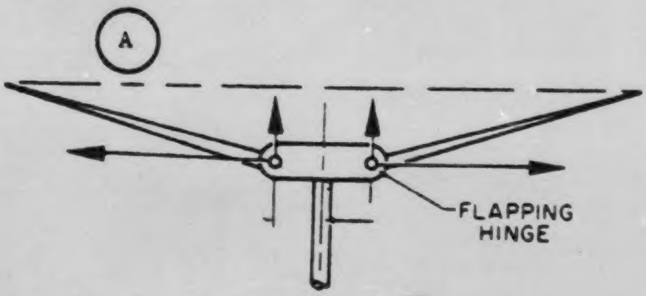
3. This difference in lift, caused by the forward flight of the aircraft, is dissymmetry of lift. The difference in the lift of the advancing and retreating blades is called ____________________ ____________________.

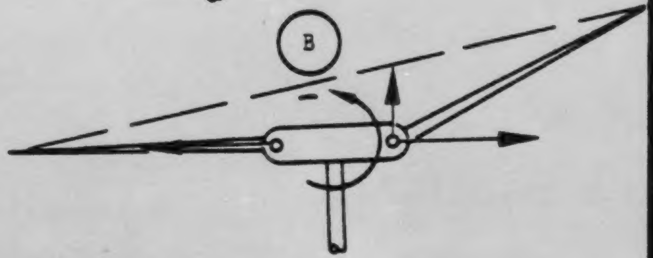
4. Dissymmetry of lift is ____________________ ____ ____

Turn to page 25, frame A, for correct response.

5. Now that we have this dissymmetry of lift, what are we going to do with it? It sure makes for crazy flying, so we must take care of it someway, somehow.

Take a look at the illustrations below. Assume the tip speed is 300 m.p.h., and we have a forward speed of 100 m.p.h.



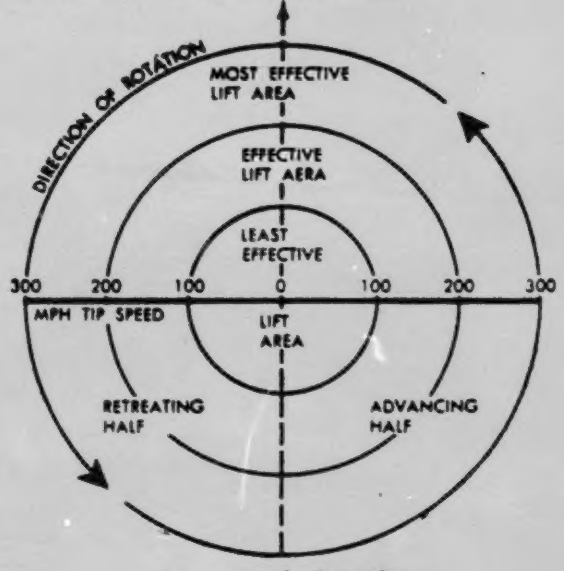


Frame 5 continued on next page.

5. (Con.)

In illustration A, there is dissymmetry of lift. In illustration B, the advancing blade has flapped up. Will this cause the tip speed to increase or decrease? ________________

6. When the blade flaps up as it did in illustration B, it will naturally have a lower tip speed because of the shorter distance that it has to travel. This lower tip speed will decrease lift, as shown in the illustration below.


DIRECTION OF ROTATION
MOST EFFECTIVE LIFT AREA
EFFECTIVE LIFT AERA
LEAST EFFECTIVE
300
200
100
0
100
200
300
MPH TIP SPEED
LIFT AREA
RETREATING HALF
ADVANCING HALF

Zero Airspeed—Symmetry

a. Note: The blade has a shorter distance to travel. Dissymmetry of lift is corrected for by allowing the blades to __________.

7. How does flapping correct for dissymmetry of lift?

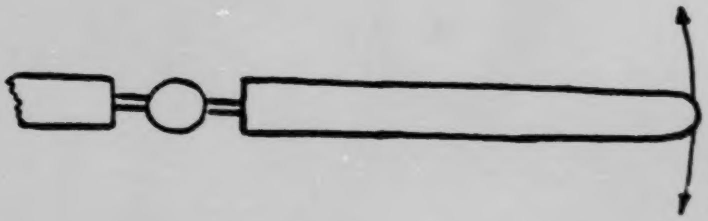
____

____

____

Turn to page 25, frame B, for correct response.

8. In the preceding frames, the flapping movement of the blades has been discussed. Another movement of the blade is HUNTING (leading and lagging).



We allow the blades to move fore and aft a slight amount, as shown in the illustration above.

The process of allowing the blades to lead and lag is called _________________.

9. As you can remember from part I, a helicopter has drag. Well, so do the individual rotor blades. This process of hunting allows for varying degrees of drag on the rotor blades. It also aids in autorotation.

Why are the rotor blades allowed to hunt?

Turn to page 25, frame C, for correct response.

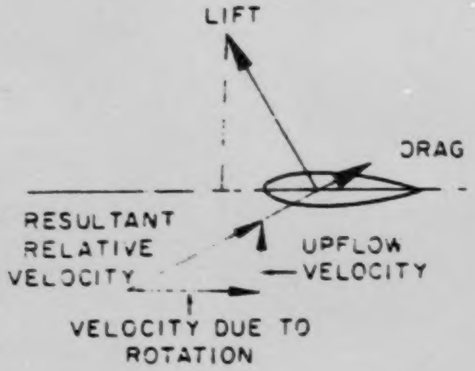
10. Autorotation, often called "windmilling," is the process of producing lift with airfoils which rotate freely as the air passes from the bottom up through the rotor system.

The helicopter uses autorotation for emergency landings in case of engine failure.

11. When a helicopter autorotates, air passes upward through the rotor system, and the blades go to the full lead position.

The blade angle must be kept low to minimize drag. The resultant lift is then ahead of the axis of rotation, as shown below.

FORCES IN THE
AUTOROTATION REGION


LIFT
DRAG
RESULTANT
RELATIVE
VELOCITY
UPFLOW
VELOCITY
VELOCITY DUE TO
ROTATION

This will cause the blade to produce lift and, at the same time, keep the blades rotating.

During autorotation, the resultant lift is _____________ of the axis of rotation.

12. What is autorotation?

____

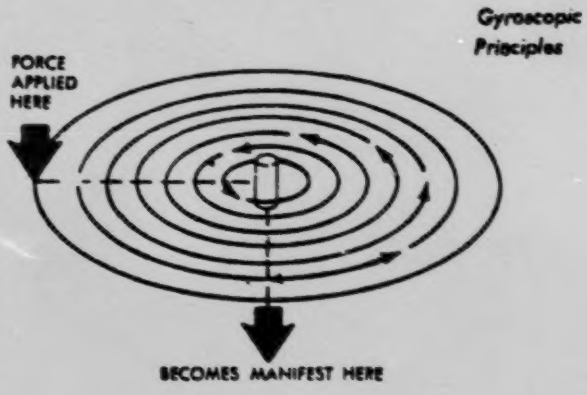
____

____

Turn to page 25, frame D, for correct response.

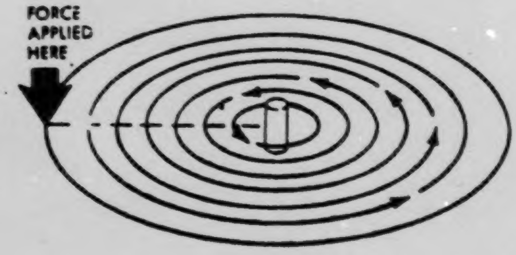
13. One of the physical laws that play a very important role in control of the helicopter is the angle of gyroscopic precession.

Take a close look at the illustration below.


Gyroscopic Principles
FORCE APPLIED HERE
BECOMES MANIFEST HERE

How many degrees are there between the point where the force is applied? ________________

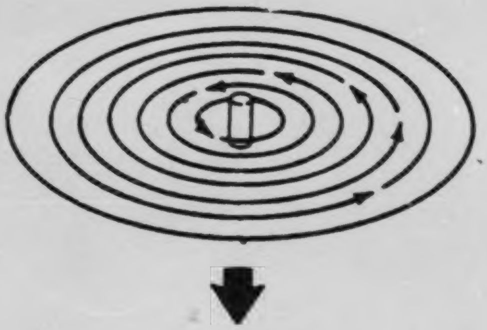
14. Action always takes place 90° in the direction of rotation. In the illustration below, indicate by an arrow the direction and point where the action will take place.



Turn to page 25 , frame E, for correct response.

15. You can see this would create a problem for the pilot if he could not compensate for gyroscopic precession. The illustration below shows that the control linkage is offset from the blade by 90°. This will cause the desired action to occur when the blade reaches the point where the force is applied.

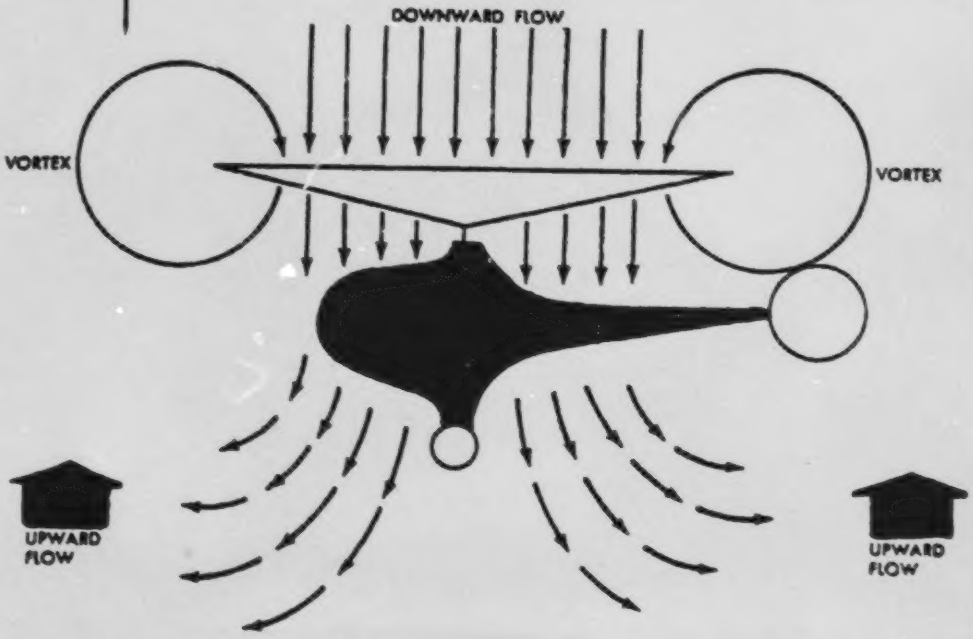
On the illustration below, place an arrow at the point where force must be applied to get the desired action, as shown.



Turn to page 26, frame M, for correct response.

16. Power settling is an uncontrollable loss of altitude that occurs during a high rate of descent at low airspeed.

The picture below shows the downwash recirculating through the outer rim of the rotor disc.


DOWNWARD FLOW
VORTEX
VORTEX
UPWARD FLOW
UPWARD FLOW

Power Settling

The outer part of the blade illustrated above is in a ______________.

17. This vortex causes loss of lift, and the uncontrollable loss of altitude is called

______________ ______________.

18. What is power settling?

____

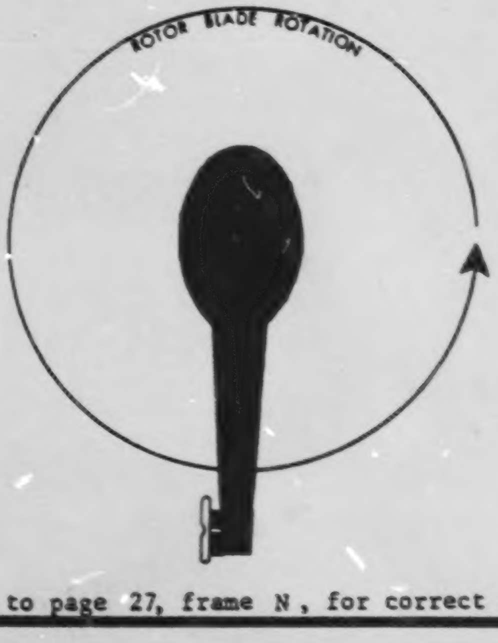
____

Turn to page 25, frame F, for correct response.

19. The torque reaction of the drive system for the main rotors is another important consideration. The torque attempts to turn the fuselage in the opposite direction of the rotor blades.

This is one of Newton's laws, which states for every action there is an equal and opposite reaction.

In the illustration below, you see that the direction of rotation of the rotors is indicated. (Show with an arrow the direction in which torque is trying to turn the fuselage.)



Turn to page 27, frame N, for correct response.

20. What effect does torque have on the helicopter?

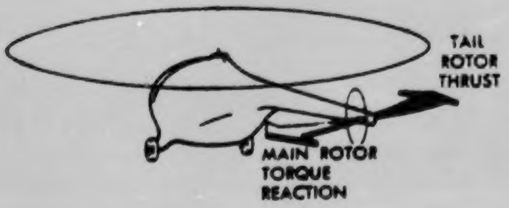
____

____

Turn to page 25 , frame G,for correct response.

21. This torque must be counteracted in some manner. Each type of rotor configuration uses a different method, so we will take up the single-rotor configuration first. You have seen that all single-rotor helicopters have a tail rotor.

This tail rotor creates thrust in the opposite direction of torque, as shown in the illustration below.



In this occasion, what is the purpose of the tail rotor? ________________________________

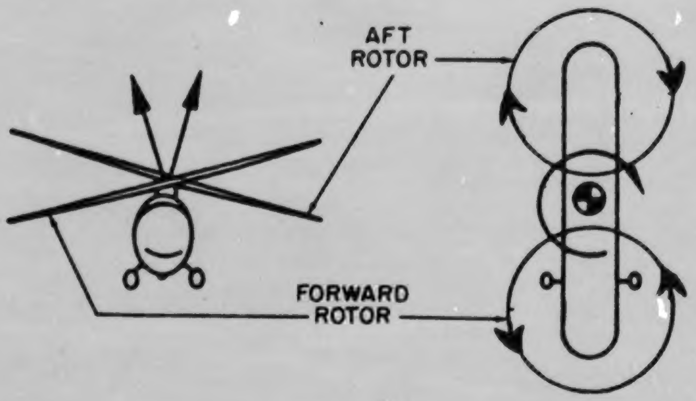
22. How is torque compensated for in single-rotor helicopters?

____

____

____

23. In all of the other types of rotor configurations, the problem of torque is eliminated by turning the rotors in opposite directions, as shown by the tandem configuration below.



What counteracts torque in a tandem-rotor helicopter?

____

____

24. This turning in opposite directions is called counterrotating.

a. How is torque counteracted in a single-rotor helicopter?

____

____

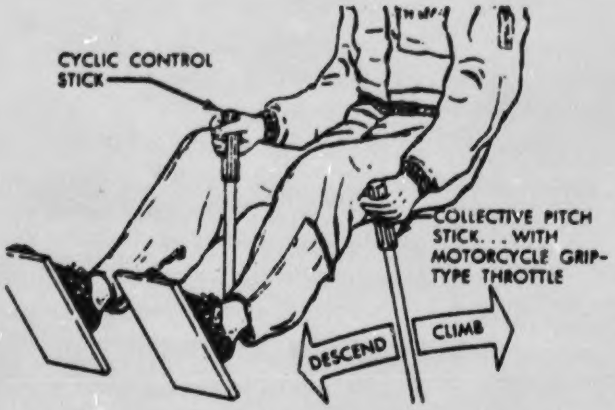
b. How is torque counteracted in all types of helicopters, excluding the single-rotor configuration?

____

____

Turn to page 25, frame H , for correct response.

25. Tail rotor thrust is controlled by the rudder pedals. But what are those other two sticks in the cockpit, as shown in the illustration below?


CYCLIC CONTROL STICK
COLLECTIVE PITCH STICK... WITH MOTORCYCLE GRIP-TYPE THROTTLE
DESCEND
CLIMB

Let's take up the collective stick first. This is a real descriptive word for this control, because its purpose is to change the pitch of all the rotor blades the same amount at the same time (collectively).

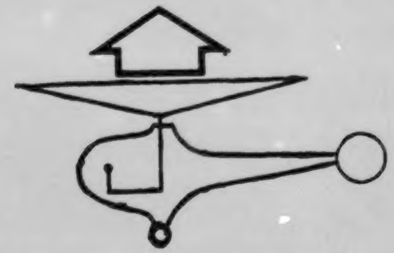
What does the collective stick do?

____

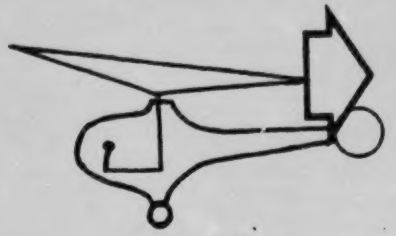
____

Turn to page 26 , frame J, for correct response.

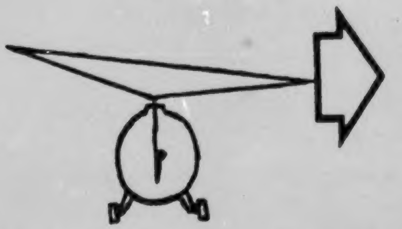
26. Now for the cyclic stick. This is the control which the pilot uses to tilt the tip-path plane. This will determine his direction of flight as shown below.



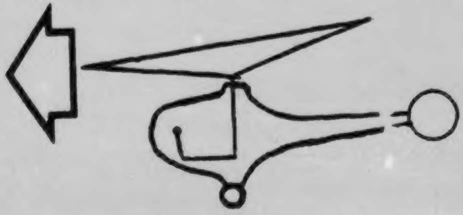
VERTICAL FLIGHT



BACKWARD FLIGHT



SIDEWARD FLIGHT



FORWARD FLIGHT

This cyclic stick tilts the ____________________

______________________________.

27. What is the purpose of the cyclic control?

____

____

____

Turn to page 26, frame I , for correct response.

28. What is the purpose of the collective pitch control?

____

____

____

Turn to page 26, frame J , for correct response.

29. Atmosphere has an effect on the helicopter in flight, just as it does on a fixed-wing aircraft. Air density is the major problem. As the air becomes less dense, lift decreases; therefore, as the air becomes more dense, lift will ____________.

30. What effect does air density have on helicopter flight?

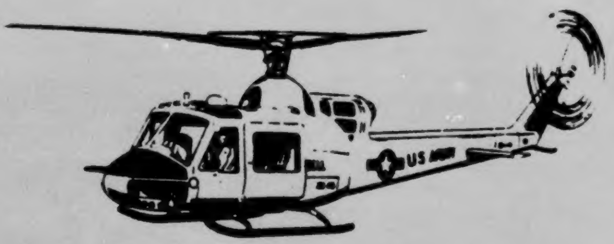
____

____

____

Turn to page 26,frame K, for correct response.

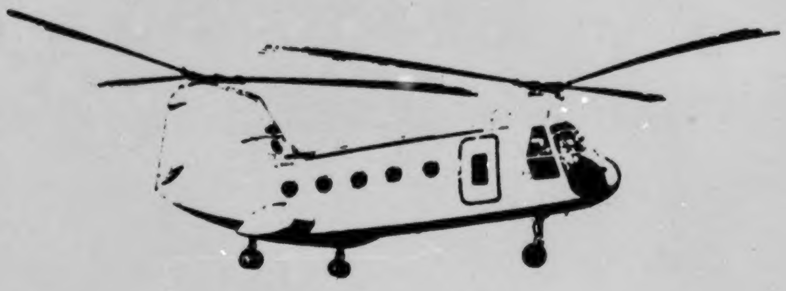
31. We have talked about rotor configurations, but just what are they? The illustration below shows the one we have talked about during this lesson-- the single-rotor, so called because it has only one main rotor.



The helicopter shown above is of the

__________________-rotor configuration.

32. This is the tandem (fore and aft) configuration.

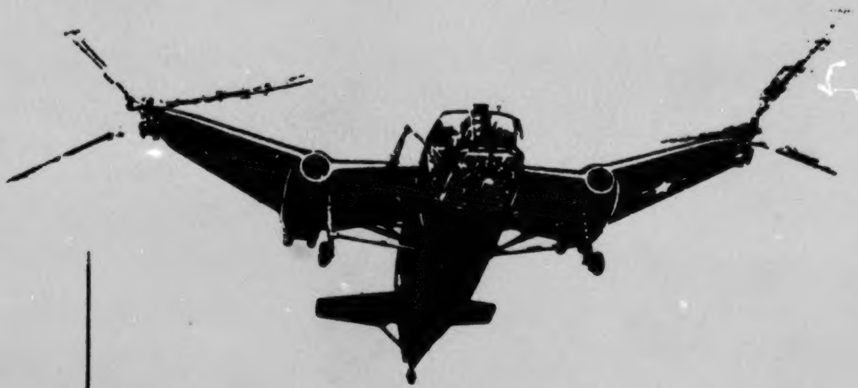


The helicopter shown above is the ____________-

rotor type.

33. This is the lateral-rotor (side-by-side)

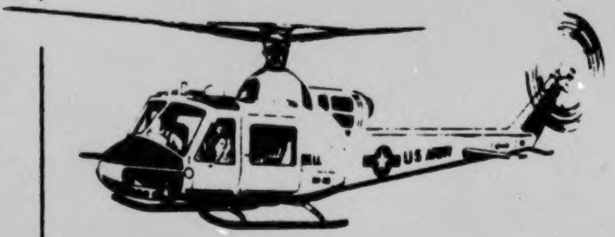
configuration.



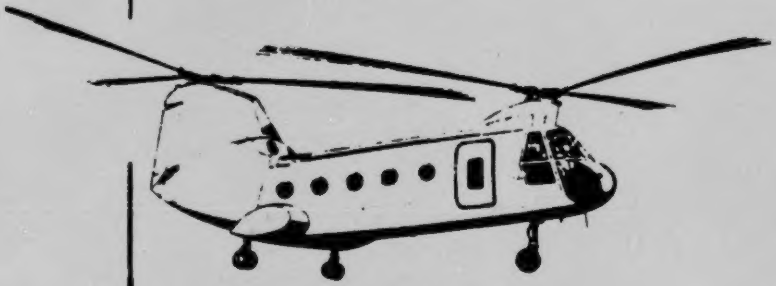
The helicopter shown above is the ___________-

rotor type.

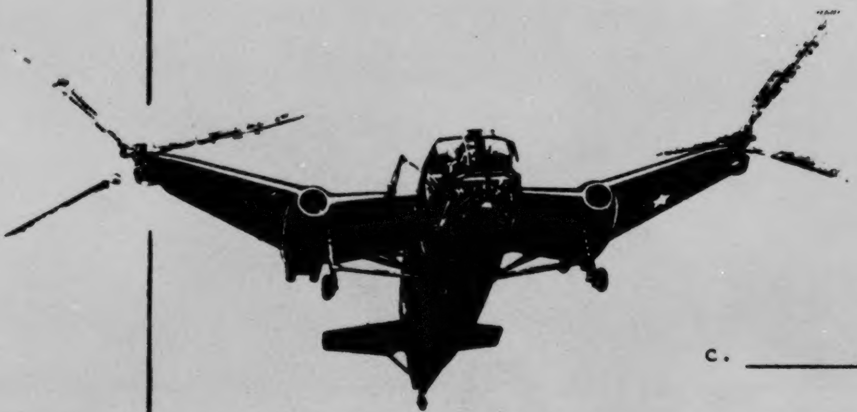
34. Label the three types of helicopters shown below.



a. ____________

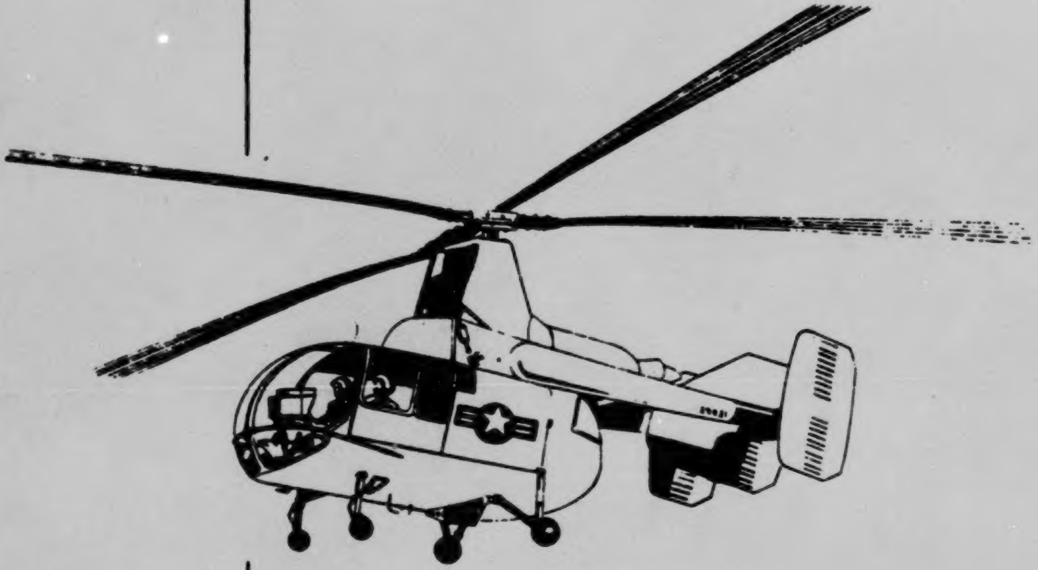


b. ____________



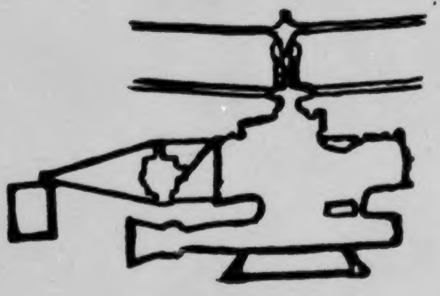
c. ____________

35. Pictured here is a synchropter (intermeshing) type of helicopter. Note that the blades are synchronized to turn much like an egg beater.



This is a ______________________ type of helicopter.

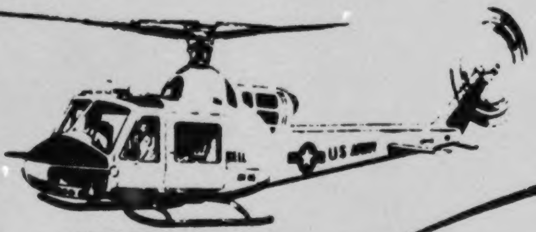
36. The last type is the coaxial (one-atop-the-other) configuration.



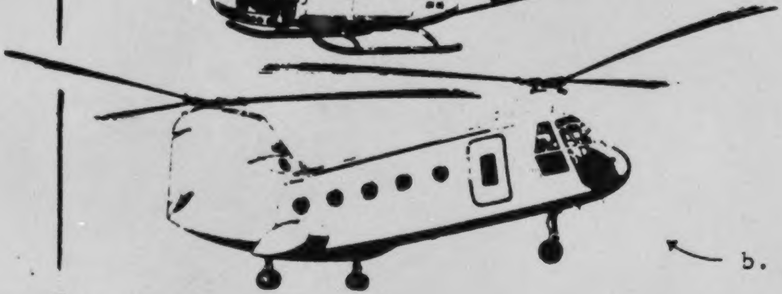
The helicopter pictured above is the

_____________-rotor type.

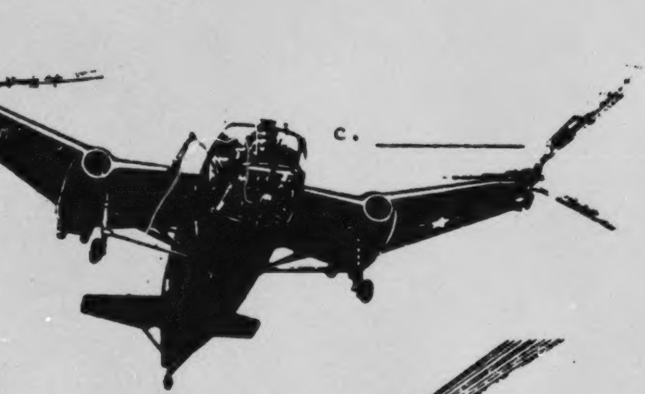
37. Label the helicopters pictured below.



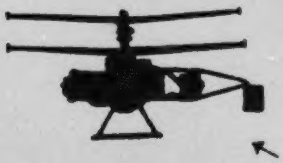
a. ________



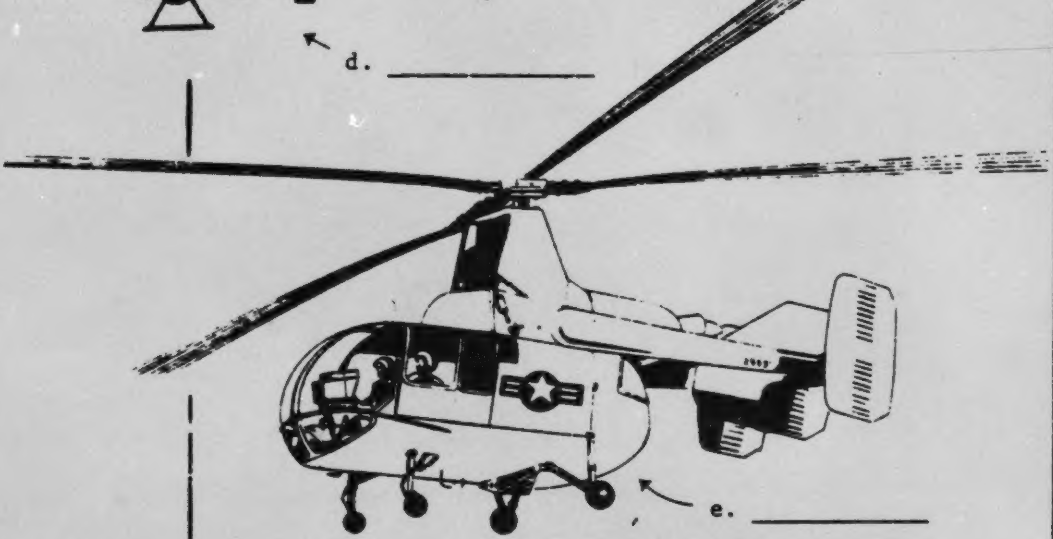
b. ________



c. ________



d. ________



e. ________

Turn to page 26, frame L, for correct response.

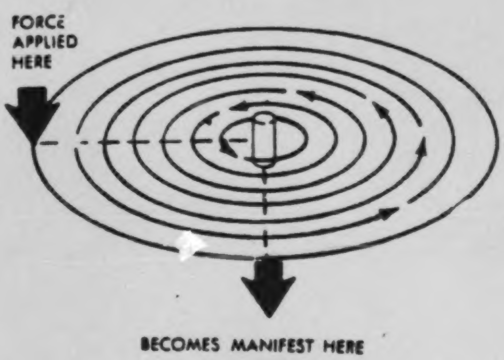
A. the difference in lift between the advancing and retreating blades.

B. Lowers the speed of the advancing blade.

C. Allows for varying degrees of drag on the rotor blades.

D. The process of producing lift with airfoils which rotate freely.

E.



F. Uncontrolled loss of altitude because of the blade tips turning in their own vortex.

G. Torque tries to turn the airframe opposite to the direction of rotor rotation.

H. a. By the use of a tail rotor.

   b. By turning the rotors in opposite directions.

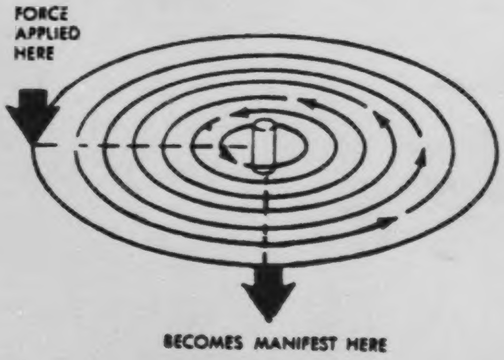
I. Gives the pilot control of directional flight.

J. Changes the pitch of all rotor blades the same amount at the same time.

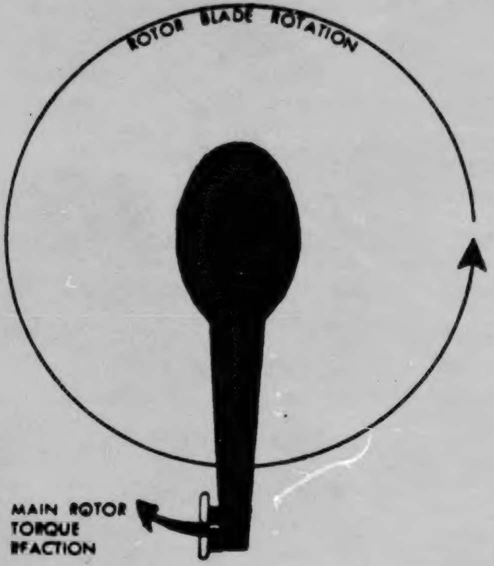
K. As air becomes more dense, lift will increase; as the air becomes less dense, lift will decrease.

L. a. Single-rotor
   b. Tandem-rotor
   c. Lateral-rotor
   d. Coaxial-rotor
   e. Synchropter

M.


FORCE APPLIED HERE
BECOMES MANIFEST HERE

N. Clockwise


ROTOR BLADE ROTATION
MAIN ROTOR TORQUE REACTION

HELICOPTER FUNDAMENTALS
PART II

ROTARY-WING AERODYNAMIC EFFECTS

Review Examination

1. What is dissymmetry of lift?

____

____

____

2. Why does flapping correct for dissymmetry of lift?

____

____

____

3. Why must the blades be allowed to hunt?

____

____

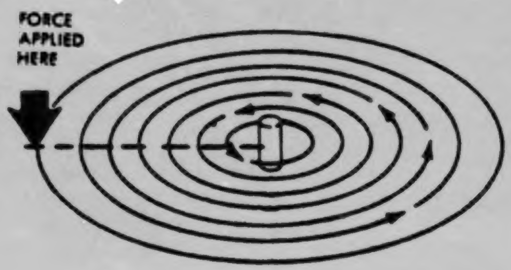
4. What is autorotation?

____

____

____

5. On the drawing below, place an arrow where the action will take place.



6. What is power settling?

____

____

7. What effect does torque have on the helicopter?

____

____

8. How is torque counteracted on a single-rotor helicopter?

____

____

9. How is torque counteracted on a multirotor helicopter?

____

____

10. What is the purpose of the collective pitch control?

____

____

11. What is the purpose of the cyclic pitch control?

____

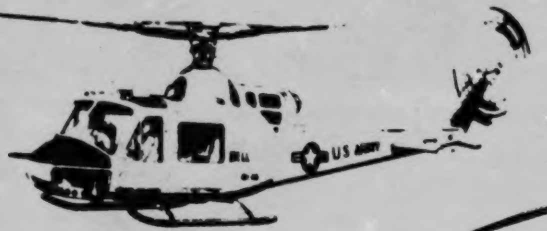
____

12. What effect does atmospheric density have on helicopter operation?

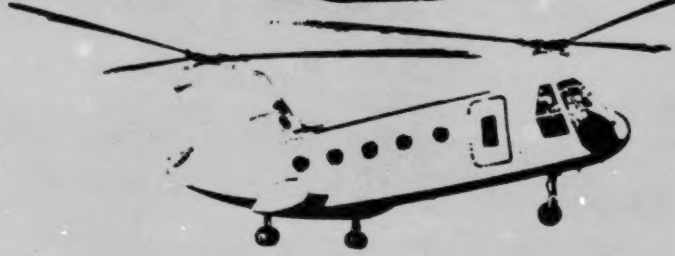
____

____

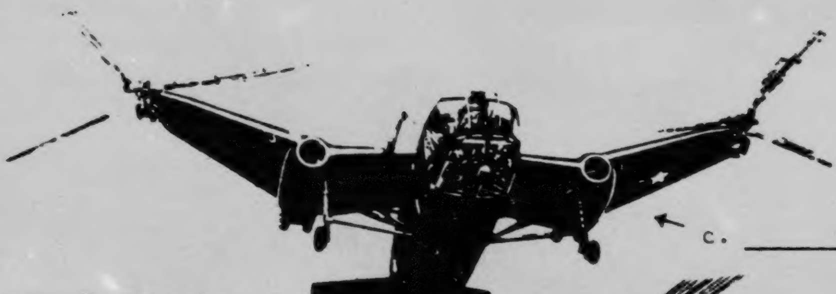
13. Label the drawings below as to the type of rotor configuration.



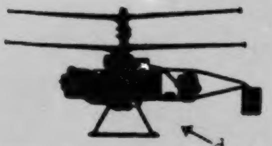
a. ____________



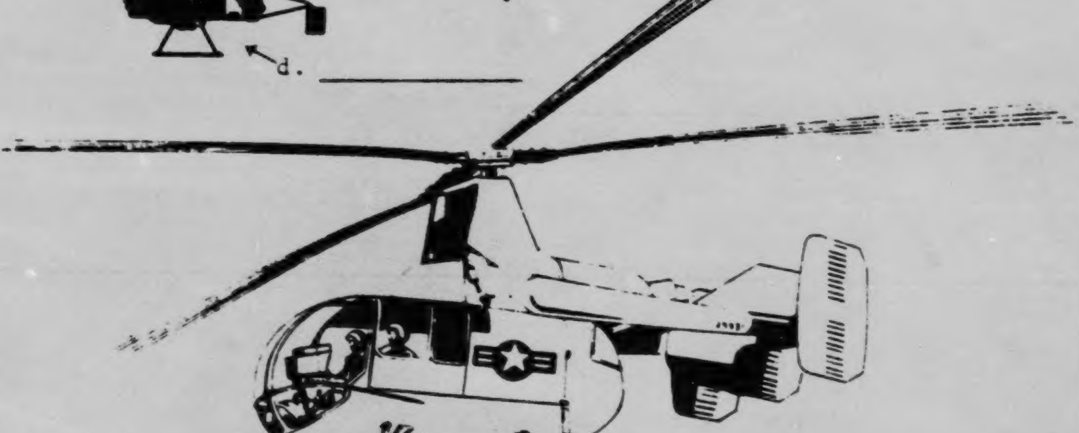
b. ____________



c. ____________



d. ____________



e. ____________

314

PROGRAMMED INSTRUCTION

2-5

Basic Electricity Review

Part VI

PARALLEL CIRCUITS

Aviation Training Division
USCG-AR&SC-Elizabeth City, N. C.

BASIC ELECTRICITY REVIEW

PART VI

PARALLEL CIRCUITS

INSTRUCTIONS

This is a programmed lesson. It is designed to teach, not to test. You will need only this booklet, a pencil, and some time to complete this lesson. If there is something in the program you do not understand, ask your instructor or supervisor for assistance.

- REMEMBER -

This lesson has been written so that the amount of reading necessary is minimal and yet most meaningful. Therefore, it is very important that you follow these instructions.

- Read each page carefully.
- Fill in each blank.
- Keep the answer to the frame on which you are working covered with a slip of paper until you have written your answer.
- Correct all errors you make.
- Follow all directions given in the program.

SUGGESTED READING TIME
75 MINUTES

BASIC ELECTRICITY REVIEW

PART VI

PARALLEL CIRCUITS

OBJECTIVES

1. From a list of statements pertaining to circuits, select the statements which apply to parallel circuits.

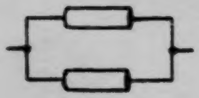
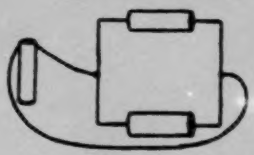
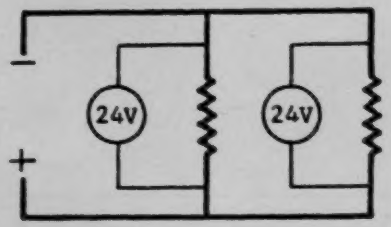
2. Solve problems in parallel circuits for the following:

   a. Total resistance
   b. Resistance of an individual branch
   c. Total current
   d. Current flow of an individual branch
   e. Total voltage

3. Given a list of numbers, determine the reciprocal of each.

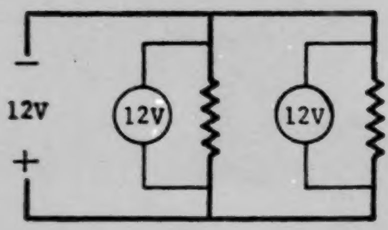
INTRODUCTION

Series circuits are becoming more obsolete in aircraft as each day goes by. However, series circuits are stepping stones for the more complex circuits found in today's aircraft; and in order to understand the other types of electrical circuits, you must understand series circuits first. When building a house, you must start with the foundation; and when studying circuitry, you must begin at the foundation-- series circuits. Now that you have the foundation, let's build the ground floor with parallel circuits.

	1. Resistances side by side and with their ends connected  are parallel-connected. If the resistances in a circuit are so connected,  the circuit is known as a __________ circuit.
PARALLEL	2. The resistances in a parallel circuit are connected parallel to each other. Each of these resistances will be a branch. If a twelve-volt battery was the source voltage of a parallel circuit, the voltage in each branch of that parallel circuit would also equal twelve volts. The voltage of each branch of a parallel circuit equals the __________ voltage.
SOURCE	3. The voltage in each branch of a parallel circuit will equal source voltage.  What is the source voltage in the circuit above? ______ volts

24 VOLTS

4.



PARALLEL CIRCUIT LAW FOR TOTAL VOLTAGE

$E_t = E_1 = E_2 = E_3 \ldots.$

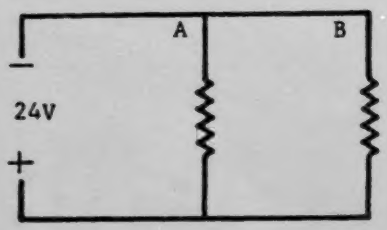
In the illustration above, the source voltage and branch voltages are ________________.
(equal/unequal)

EQUAL

5. Put the ×, +, ÷, or = sign in the parentheses to make the statement correct.
Since source voltage (total voltage) and branch voltages are equal, the parallel circuit law for total voltage is $E_t(\ )\ E_1(\ )\ E_2(\ )\ E_3(\ )$, etc.

$E_t=E_1=E_2=E_3$

6. The voltage is the same across each branch of a parallel circuit, and the voltage of each branch equals source voltage.



What is the voltage in branch A and what is the voltage in branch B above?

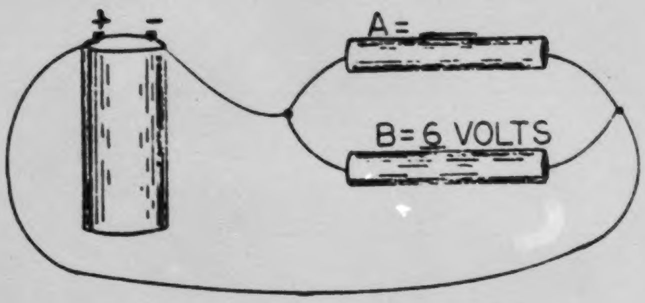
A. ____________

B. ____________

A. 24 VOLTS

B. 24 VOLTS

7.



a. What is the voltage in branch A? ____________

b. What is the source voltage? ______________

---

a. 6 VOLTS

b. 6 VOLTS

8. Now that you know that all the branch voltages and the source voltage are equal in a parallel circuit, you will find that solving for total (source) voltage is relatively easy. You can determine total voltage (source voltage) in a parallel circuit by applying Ohm's law. If you multiply the current of a branch by the resistance of that branch, you will determine the ________________________.

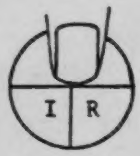
SOURCE VOLTAGE
OR
TOTAL VOLTAGE
OR
BRANCH VOLTAGE

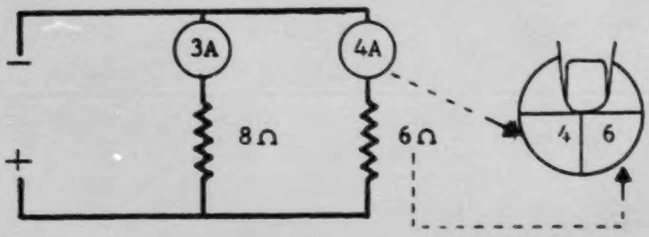
(THEY ARE ALL EQUAL.)

9. Total voltage in a parallel circuit can be determined by multiplying the current of a branch by the resistance of the same branch. Complete the example below.

Step 1 ---

Step 2 ---





Step 3 --- ____ × ____ = E_t

E_t = ____ volts

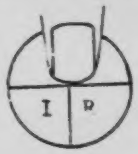
STEP 3

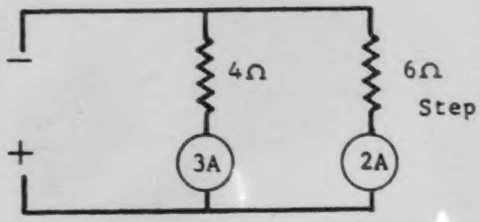
4 × 6 = E_t

E_t = 24 VOLTS

10. Using the information in the illustration below, complete the steps and find total voltage (E_t).

Step 1 ---



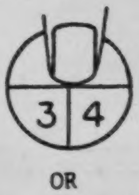


Step 2 ---

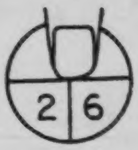
Step 3 ---____ × ____ = E_t

E_t = _____ volts

STEP 2



OR



STEP 3

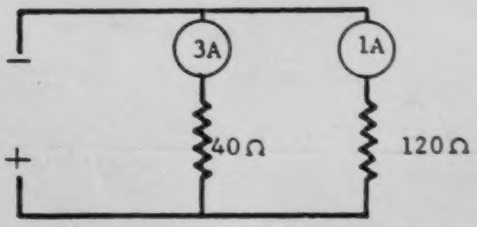
3 × 4 = E_t

OR

2 × 6 = E_t

E_t = 12 VOLTS

11. Solve for total voltage in the parallel circuit below.


−
+
3A
1A
40Ω
120Ω

E_t = ________ volts

120 VOLTS

12. As you probably have noticed in this program, the difference between a parallel circuit and a series circuit is that a parallel circuit has two or more paths for current. Knowing this, you can now understand why an open in a parallel circuit only affects the branch or branches in which the open occurs.

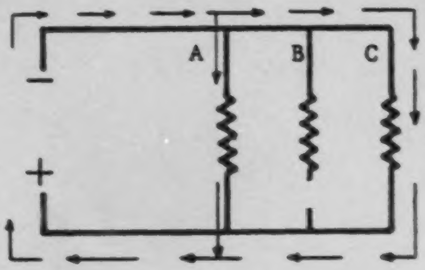


Figure 1

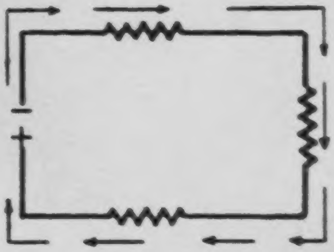


Figure 2

a. Which of the illustrations above shows a parallel circuit? ______________

b. A parallel circuit has ________ or ________ paths for current.

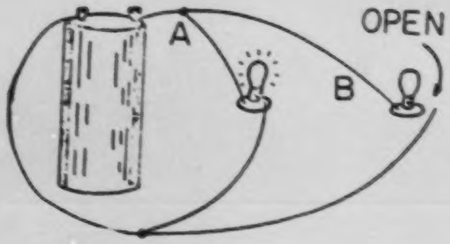
c. Which branch of the parallel circuit above contains an open? ____________________

a. FIGURE 1

b. TWO OR MORE

c. BRANCH B

13. What effect will the open in branch B have on the light bulb in branch A?



a. The bulb will burn brighter.

b. The bulb will get dimmer.

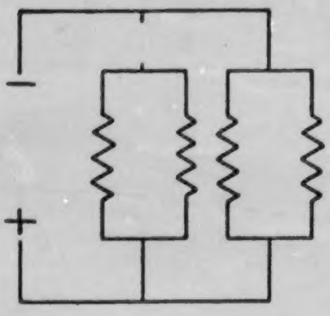
c. No affect.

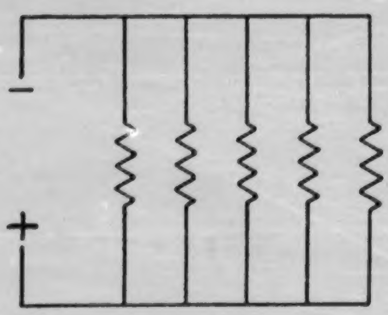
c.

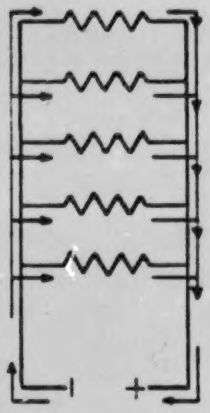
14. The reason the open has no effect on the bulb in branch A is that an open in a parallel circuit affects only the ____________ or ______________ in which the open occurs.

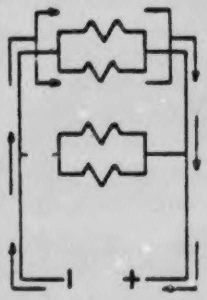
BRANCH OR BRANCHES

15. Draw arrows to indicate the path of current flow in the parallel circuits below.

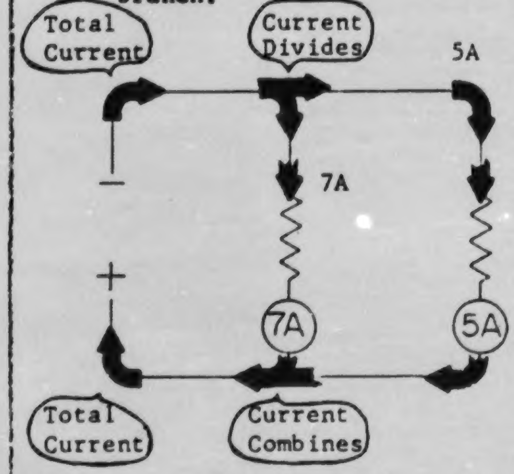








16. Since a parallel circuit has two or more paths for current flow, the amount of current in each branch may be different. To find the total current (I_t) in a parallel circuit, add the current of each branch.

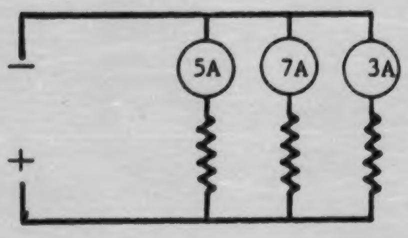
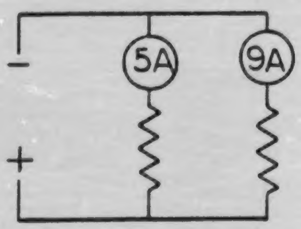
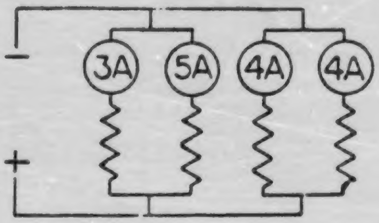
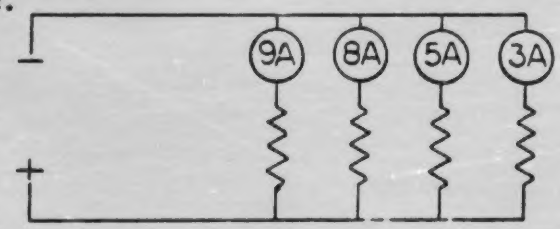

Total Current
Current Divides
5A
7A
−
+
7A
5A
Total Current
Current Combines

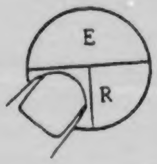
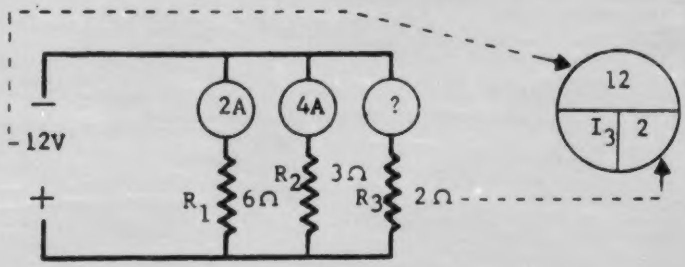
PARALLEL CIRCUIT LAW FOR TOTAL CURRENT

$I_t = I_1 + I_2 + I_3 \ldots.$

a. To find total current (I_t) in a parallel circuit, the current of all the branches should be ____________.

b. Find the total current (I_t) in the circuit above. I_t = ______________ amps.

a. ADDED b. I_t = 12 AMPS.	17. If current in each individual branch is known, total current (I_t) in a parallel circuit can be determined by ____________ the current of the individual branches.
ADDING	18. What is the total current for the parallel circuit below? I_t = __________ amps. 
I_t = 15 AMPS.	19. Find the total current in the circuits below. a.  I_t = ________ amps b.  I_t = ________ amps. c.  I_t = ________ amps.

a. I_t= 14 AMPS. b. I_t= 16 AMPS. c. I_t= 25 AMPS.	20. There may be times when branch current is unknown in a parallel circuit. Determining branch current is a simple application of Ohm's law. If you divide the applied voltage by the resistance of a branch, you will determine the branch ___________.
CURRENT	21. In order to find the current of a branch, divide the applied voltage by the resistance of that branch. Complete the steps below and determine the current for branch 3 (I_3). Step 1 ---  Step 2 ---  2A 4A ? -12V + R_1 6Ω R_2 3Ω R_3 2Ω 12 I_3 2 Step 3 --- ____+____= I_3 I_3 = _____ amps.

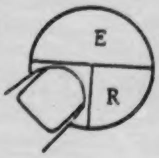
STEP 3

$12 \div 2 = I_3$

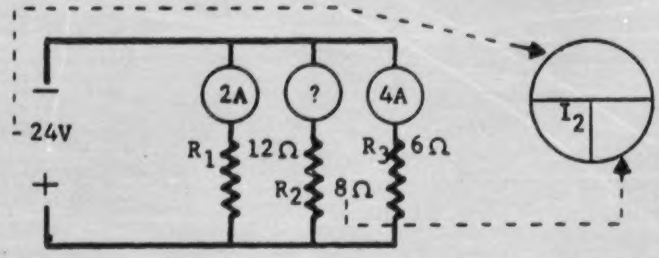
$I_3 = 6$ AMPS.

22. Using the information in the illustration below, determine the current for branch 2 (I_2).

Step 1 ---



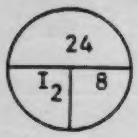
Step 2 ---


24V
2A
?
4A
R1
12Ω
R2
8Ω
R3
6Ω
I2

Step 3 --- ____÷____ = I_2

I_2 = ____ amps.

STEP 2

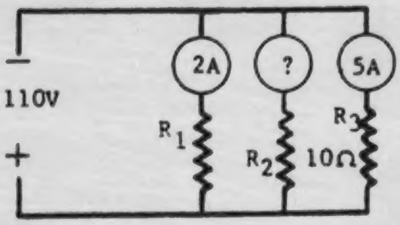


STEP 3

$24 \div 8 = I_2$

$I_2 = 3$ AMPS.

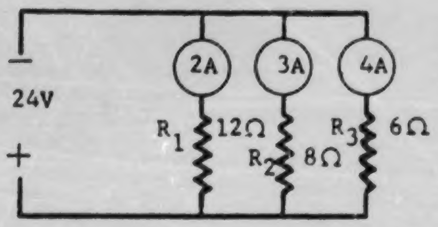
23. Find I_2 in the circuit below.


110V
2A
?
5A
R1
R2
R3
10Ω

I_2 = _______ amps.

I_2 = 11 AMPS.

24. You have been solving for current in the preceding frames by dividing the applied voltage by the resistance. Look at the illustration below and study the relationship between current and resistance in each branch.



You can readily see that as resistance becomes larger, current becomes smaller. As resistance decreases, current ________________.

INCREASES

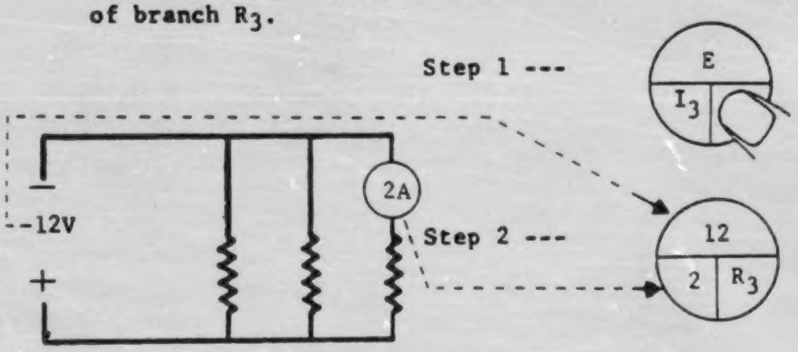
25. Current in each branch of a parallel circuit depends on the ______________ in that branch.

RESISTANCE

26. Finding the resistance of a branch in a parallel circuit is similar to finding current. When you divide the applied voltage by the current of a branch, you determine the ________________ of that branch.

RESISTANCE

27. In order to determine the resistance of a branch in a parallel circuit, divide the applied voltage by the current in that branch. Complete the steps in the example below, and determine the resistance of branch R_3.



Step 3 --- ___ ÷ ___ = R_3

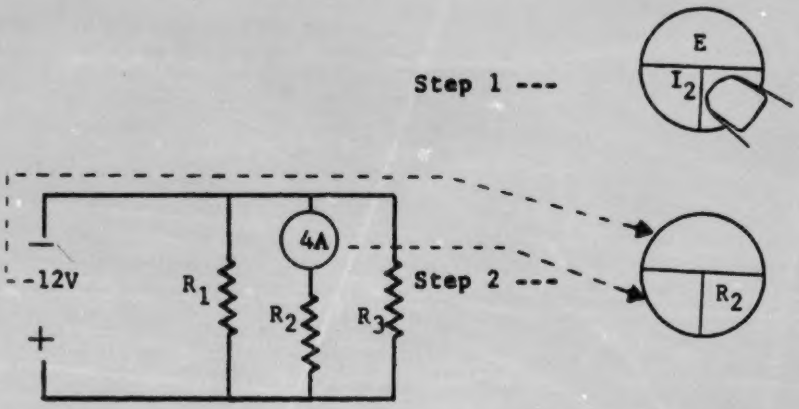
R_3 = ____ ohms

STEP 3

$12 \div 2 = R_3$

$R_3 = 6$ OHMS

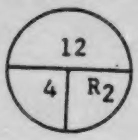
28. From the information given below, complete the steps and find R_2.


Step 1 ---
E
I_2
-12V
+
R_1
4A
R_2
R_3
Step 2 ---
R_2

Step 3 --- ____÷____ = R_2

R_2 = ______ ohms

STEP 2

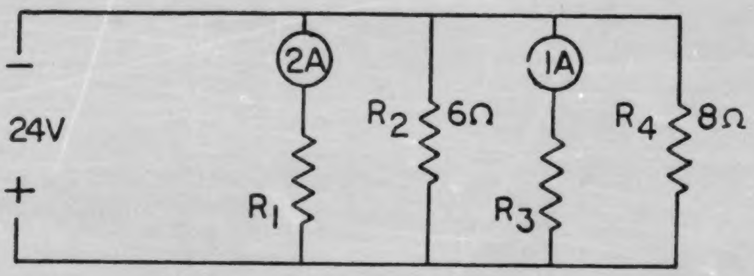


STEP 3

$12 \div 4 = R_2$

$R_2 = 3$ OHMS

29. Using the current, voltage, and resistance laws you have learned thus far, determine the values for the circuit below.


24V
2A
R_1
R_2
6Ω
1A
R_3
R_4
8Ω

R_1 = ______ ohms

R_3 = ______ ohms

I_2 = ______ amps.

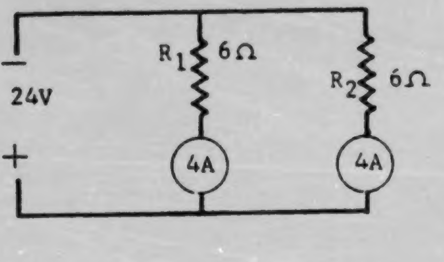
I_4 = ______ amps.

E_4 = ______ volts

I_t = ______ amps.

R_1 = 12 OHMS
R_3 = 24 OHMS
I_2 = 4 AMPS.
I_4 = 3 AMPS.
E_4 = 24 VOLTS
I_t = 10 AMPS.

30. Before we start finding the total resistance of a parallel circuit, here is something to remember. The total resistance of a parallel circuit will always be less than the smallest branch resistance of the circuit.



The total resistance of the circuit above will be

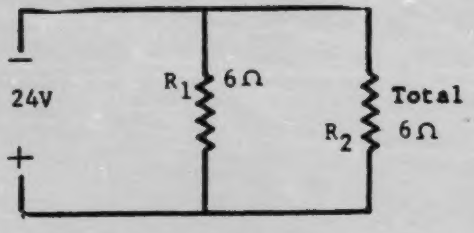
a. 6 ohms.
b. 12 ohms.
c. less than 6 ohms.
d. more than 6 ohms.

c.

31. Resistances in parallel are like water pipes in parallel. In each case, when the total size is increased, then the total resistance to current flow is decreased. Two water pipes of equal size placed side by side carry twice as much water as a single pipe of the same size; and equal resistances connected side by side pass twice as much current as a single resistance. This greater current flow in a parallel circuit indicates that total resistance is ____________ than that of a single resistance.

LESS
(SMALLER)

32. When you figure the resistance values in a parallel circuit, you will find that total resistance is always smaller than the resistance of the smallest branch.



Total resistance = 3 ohms

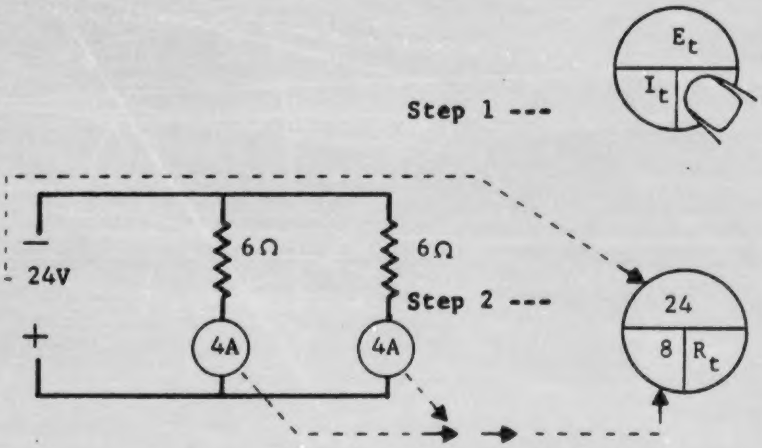
In the illustration above, the total resistance is ____________ than the smallest branch resistance.

SMALLER (LESS)

33. Since you now know that total resistance in a parallel circuit is less than the resistance of the smallest branch, it is easy to see that you cannot add individual resistances to find total resistance. Finding total resistance is another application of Ohm's law. If you were to divide total voltage (E_t) by the total amperage (I_t), you would determine ______________________.

TOTAL RESISTANCE

34. One way of finding the total resistance (R_t) of a parallel circuit is to divide the total voltage (E_t) by the total current (I_t). Complete the steps below to determine total resistance (R_t).



Step 3 --- ____ + ____ = R_t

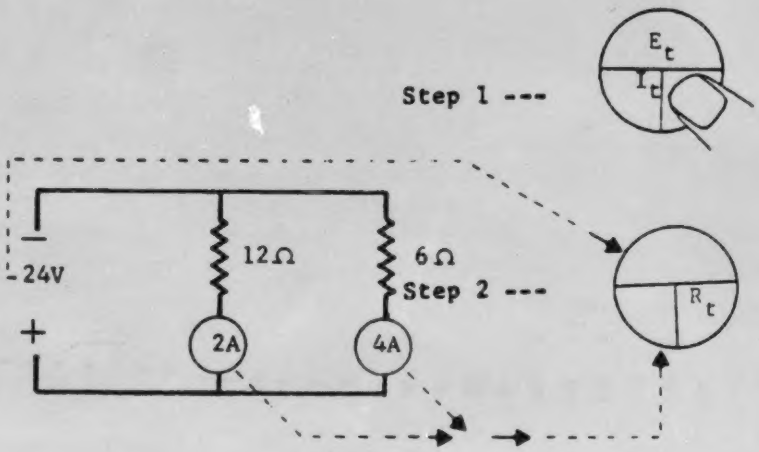
R_t = ______ ohms

STEP 3

$24 \div 8 = R_t$

R_t = 3 OHMS

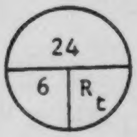
35. Using the information in the illustration below, find the total resistance (R_t) of the circuit.


Step 1 ---
E_t
I_t
24V
12Ω
6Ω
Step 2 ---
2A
4A
R_t

Step 3 --- ____ ÷ ____ = R_t

R_t = ______ ohms

STEP 2

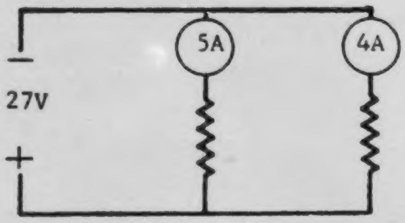


STEP 3

$24 \div 6 = R_t$

R_t = 4 OHMS

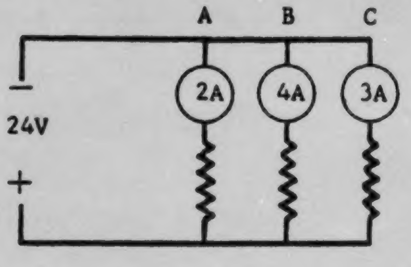
36. Find the total resistance (R_t) of the circuit below.



R_t = ________ ohms

R_t = 3 OHMS

37. Select the statements that are true if branch C of the circuit below develops an open.



a. Total resistance will increase.
b. Total resistance will decrease.
c. Total current will increase.
d. Total current will decrease.

a.

d.

38. Let's review some things we have learned about parallel circuits. Select the statements below that are correct concerning parallel circuits.

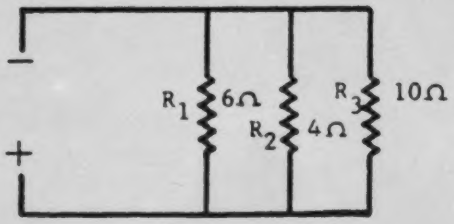
a. Voltage is the same across each branch of a parallel circuit.
b. Source voltage and branch voltage are never equal in a parallel circuit.
c. A parallel circuit has two or more paths for current.
d. The total resistance of a parallel circuit is the sum of all the branch resistances.
e. Total resistance of a parallel circuit is always less than the resistance of any branch.

a.

c.

e.

39. When the only values known in a parallel circuit are the branches' resistances, total resistance can be determined by the reciprocal method.



What method can be used to determine R_t in the circuit above? ____________________

RECIPROCAL

40. In order to find total resistance in a parallel circuit by the reciprocal method, you must first understand what is meant by reciprocal. The reciprocal of a number is that number divided into one.

Example: Find the reciprocal of 2.

Step 1 --- Set up the problem to divide the number into 1. $\frac{1}{1} \div \frac{2}{1}$

Step 2 --- Invert the divisor and change division sign to a multiplication sign. $\frac{1}{1} \times \frac{1}{2}$

Step 3 --- Multiply. $\frac{1}{1} \times \frac{1}{2} = \frac{1}{2}$

$\frac{1}{2}$ = the reciprocal of 2

Find the reciprocal of 4 by dividing it into 1.

____ = the reciprocal of 4

$\frac{1}{4}$

41. The easiest way to find the reciprocal of a whole number is to make it a fraction by giving it a numerator of one. When you do this, you have the reciprocal without performing a division process.

Example: Find the reciprocal of 4.

Give the whole number a numerator of 1. $\frac{1}{4}$ numerator / denominator

$\frac{1}{4}$ = the reciprocal of 4

Find the reciprocal for the following numbers:

a. 6 ________ b. 8 ________ c. 10 ________

a. $\frac{1}{6}$

b. $\frac{1}{8}$

c. $\frac{1}{10}$

42. Giving a whole number a numerator of one gives the ______________ for that whole number.

RECIPROCAL

43. Find the reciprocal of these whole numbers.

a. 7 __________
b. 9 __________
c. 15 __________
d. 40 __________
e. 88 __________
f. 12 __________
g. 3 __________
h. 5 __________
i. 6 __________

a. $\frac{1}{7}$

b. $\frac{1}{9}$

c. $\frac{1}{15}$

d. $\frac{1}{40}$

e. $\frac{1}{88}$

f. $\frac{1}{12}$

g. $\frac{1}{3}$

h. $\frac{1}{5}$

i. $\frac{1}{6}$

44. To find the reciprocal of a fraction, simply invert the fraction and reduce to its lowest term.

Example: $\frac{1}{2}$ inverted becomes $\frac{2}{1}$. Reduced to its lowest term it becomes 2. Then, 2 is the reciprocal of $\frac{1}{2}$.

Example: $\frac{2}{3}$ inverted becomes $\frac{3}{2}$. Reduced to its lowest term it becomes $1\frac{1}{2}$. Then, $1\frac{1}{2}$ is the reciprocal of $\frac{2}{3}$.

Find the reciprocal of the following fractions.

a. $\frac{3}{5}$ ________
b. $\frac{2}{10}$ ________
c. $\frac{1}{12}$ ________

a. $1\frac{2}{3}$ b. 5 c. 12	45. The reciprocal of a fraction will be a ________ number or a mixed number. The reciprocal of a whole number will be a ____________.
WHOLE FRACTION	46. Find the reciprocal of these fractions. a. $\frac{1}{3}$ ________ d. $\frac{1}{6}$ ________ b. $\frac{2}{7}$ ________ e. $\frac{1}{9}$ ________ c. $\frac{3}{8}$ ________ f. $\frac{4}{9}$ ________
a. 3 b. $3\frac{1}{2}$ c. $2\frac{2}{3}$ d. 6 e. 9 f. $2\frac{1}{4}$	47. To find the total resistance (R_t) of a parallel circuit when the only known values are the resistances of the branches, use the ____________ method.

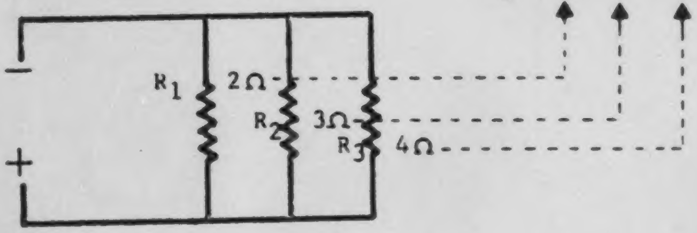
RECIPROCAL

48. Now, let's use the reciprocal method to find the total resistance (R_t) of a parallel circuit by following the steps below.

Parallel circuit law for total resistance:

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Step 1 --- $\frac{1}{R_t} = \frac{1}{2} + \frac{1}{3} + \frac{1}{4}$



Step 2 --- Find the lowest common denominator and add.

$$\frac{1}{R_t} = \frac{1}{2} + \frac{1}{3} + \frac{1}{4}$$

$$\frac{1}{R_t} = \frac{6}{12} + \frac{4}{12} + \frac{3}{12}$$

$$\frac{1}{R_t} = \frac{13}{12}$$

Step 3 --- The sum of the resistances is the reciprocal of R_t and it must be inverted.

$$\frac{1}{R_t} = \frac{13}{12}$$

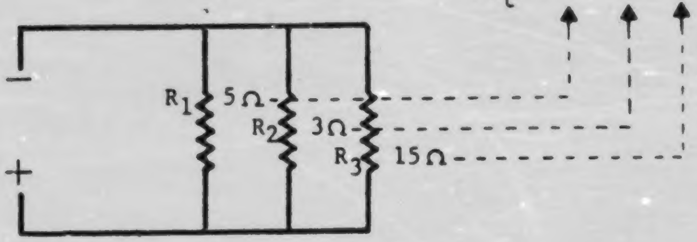
R_t = ______ohms

$R_t = \frac{12}{13}$ OHMS

49. Find the total resistance (R_t) of the parallel circuit below by completing the steps.

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Step 1 --- $\frac{1}{R_t} = \frac{1}{\ } + \frac{1}{\ } + \frac{1}{\ }$

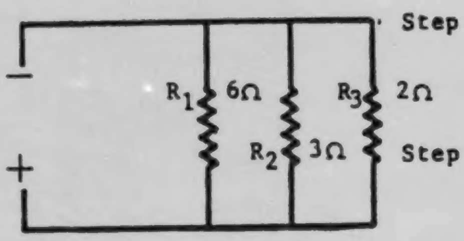
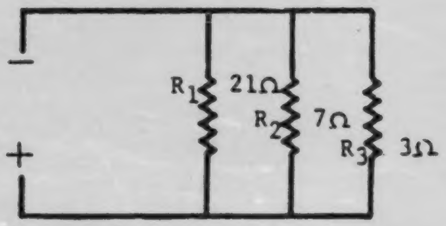


Step 2 --- Find the lowest common denominator and add.

$\frac{1}{R_t} = \frac{\ }{\ } + \frac{\ }{\ } + \frac{\ }{\ }$

Step 3 --- The sum of the resistances is the reciprocal of R_t, and it must be inverted.

R_t = ________ ohms

STEP 1 $\frac{1}{R_t} = \frac{1}{5} + \frac{1}{3} + \frac{1}{15}$ STEP 2 $\frac{1}{R_t} = \frac{3}{15} + \frac{5}{15} + \frac{1}{15}$ STEP 3 $R_t = 1\frac{2}{3}$ OHMS	50. Find the total resistance of the parallel circuit below by completing the steps.  Step 1 --- $\frac{1}{R_t}$ = ___ + ___ + ___ Step 2 --- $\frac{1}{R_t}$ = ___ + ___ + ___ Step 3 --- R_t = ______ ohms
STEP 1 $\frac{1}{R_t} = \frac{1}{6} + \frac{1}{3} + \frac{1}{2}$ STEP 2 $\frac{1}{R_t} = \frac{1}{6} + \frac{2}{6} + \frac{3}{6}$ STEP 3 $R_t = 1$ OHM	51. Find the total resistance of the parallel circuit below.  R_t = ________ ohms
$R_t = 1\frac{10}{11}$ OHMS	

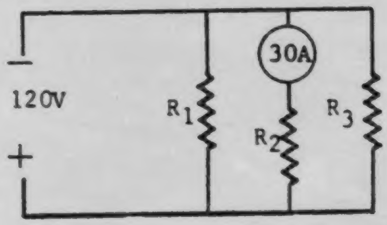
BASIC ELECTRICITY REVIEW
PART VI
PARALLEL CIRCUITS
SELF-TEST

1. A parallel circuit has (select three)

   a. only one path for current.
   b. voltage that is the same across each branch.
   c. voltage that varies between the branches.
   d. two or more paths for current.
   e. a total resistance smaller than the resistance of any branch.
   f. current that is constant throughout.

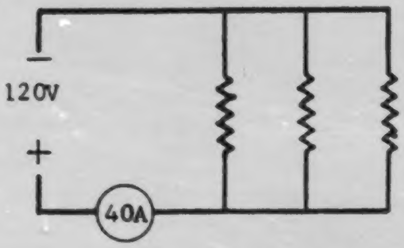
2. Solve for the unknown in each of these problems.

   a.



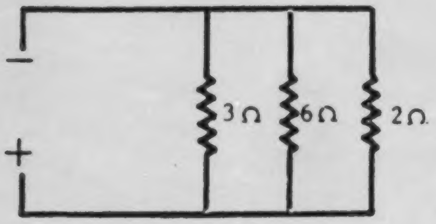
Resistance of branch 2 = ______ ohms

   b.



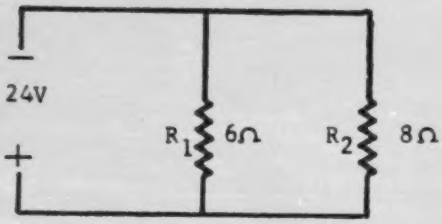
Total resistance = _____ ohms

c.



Total resistance =______ohms

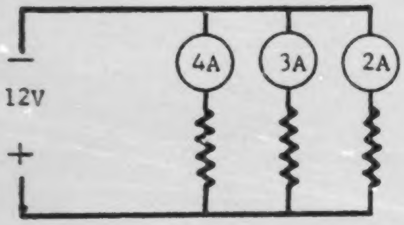
d.


−
24V
+
R_1
6Ω
R_2
8Ω

Current through R_1 = _______ amps.

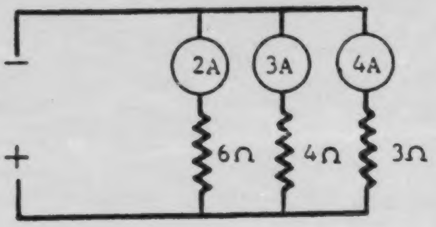
Current through R_2 = _______ amps.

e.



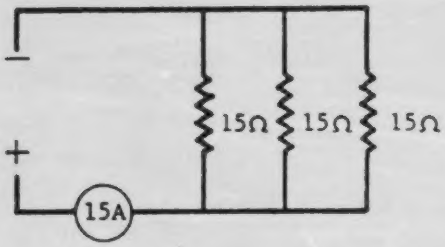
Total current = ____ amps.

f.


−
+
2A
3A
4A
6Ω
4Ω
3Ω

Total voltage = _____ volts

g.


−
+
15Ω
15Ω
15Ω
15A

Total voltage = _____ volts

3. Determine the reciprocal of each of these numbers.

5 ____________

10 ____________

8 ____________

1/2 ____________

25 ____________

1/4 ____________

Basic Electricity NAVPERS 10086-B 342

2-5

CHAPTER 2

FUNDAMENTAL CONCEPTS OF ELECTRICITY

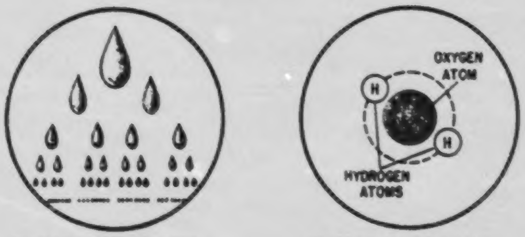
The word "electric" is actually a Greek-derived word meaning AMBER. Amber is a translucent (semitransparent) yellowish mineral, which, in the natural form, is composed of fossilized resin. The ancient Greeks used the words "electric force" in referring to the mysterious forces of attraction and repulsion exhibited by amber when it was rubbed with a cloth. They did not understand the fundamental nature of this force. They could not answer the seemingly simple question, "What is electricity?". This question is still unanswered. Though electricity might be defined as "that force which moves electrons," this would be the same as defining an engine as "that force which moves an automobile." The effect has been described, not the force.

Presently little more is known than the ancient Greeks knew about the fundamental nature of electricity, but tremendous strides have been made in harnessing and using it. Elaborate theories concerning the nature and behavior of electricity have been advanced, and have gained wide acceptance because of their apparent truth and demonstrated workability.

From time to time various scientists have found that electricity seems to behave in a constant and predictable manner in given situations, or when subjected to given conditions. These scientists, such as Faraday, Ohm, Lenz, and Kirchhoff, to name only a few, observed and described the predictable characteristics of electricity and electric current in the form of certain rules. These rules are often referred to as "laws." Thus, though electricity itself has never been clearly defined, its predictable nature and easily used form of energy has made it one of the most widely used power sources in modern time. By learning the rules, or laws, applying to the behavior of electricity, and by understanding the methods of producing, controlling, and using it, electricity may be "learned" without ever having determined its fundamental identity.

THE MOLECULE

One of the oldest, and probably the most generally accepted, theories concerning electric current flow is that it is comprised of moving electrons. This is the ELECTRON THEORY. Electrons are extremely tiny parts, or particles, of matter. To study the electron, therefore, the structural nature of matter itself must first be studied. (Anything having mass and inertia, and which occupies any amount of space, is composed of matter.) To study the fundamental structure or composition of any type of matter, it must be reduced to its fundamental fractions. Assume the drop of water in figure 2-1 (A) was halved again and again. By continuing the process long enough, the smallest particle of water possible—the molecule—would be obtained. All molecules are composed of atoms.



DIVIDING A DROP OF WATER
(A)

MOLECULE OF WATER H_2O
(B)

BE.2

Figure 2-1.—Matter is made up of molecules.

A molecule of water (H_2O) is composed of one atom of oxygen and two atoms of hydrogen, as represented in figure 2-1 (B). If the molecule of water were further subdivided, there would remain only unrelated atoms of oxygen and hydrogen, and the water would no longer exist as such. This example illustrates the following fact—the molecule is the smallest particle to which a substance can be reduced and still be called by the same name. This applies to all substances—liquids, solids, and gases.

When whole molecules are combined or separated from one another, the change is generally referred to as a PHYSICAL change. In a CHEMICAL change the molecules of the substance are altered such that new molecules result. Most chemical changes involve positive and negative ions and thus are electrical in nature. All matter is said to be essentially electrical in nature.

THE ATOM

In the study of chemistry it soon becomes apparent that the molecule is far from being the ultimate particle into which matter may be subdivided. The salt molecule may be decomposed into radically different substances—sodium and chlorine. These particles that make up molecules can be isolated and studied separately. They are called ATOMS.

The atom is the smallest particle that makes up that type of material called an ELEMENT. The element retains its characteristics when subdivided into atoms. More than 100 elements have been identified. They can be arranged into a table of increasing weight, and can be grouped into families of material having similar properties. This arrangement is called the PERIODIC TABLE OF THE ELEMENTS.

The idea that all matter is composed of atoms dates back more than 2,000 years to the Greeks. Many centuries passed before the study of matter proved that the basic idea of atomic structure was correct. Physicists have explored the interior of the atom and discovered many subdivisions in it. The core of the atom is called the NUCLEUS. Most of the mass of the atom is concentrated in the nucleus. It is comparable to the sun in the solar system, around which the planets revolve. The nucleus contains PROTONS (positively charged particles) and NEUTRONS which are electrically neutral.

Most of the weight of the atom is in the protons and neutrons of the nucleus. Whirling around the nucleus are one or more smaller particles of negative electric charge. THESE ARE THE ELECTRONS. Normally there is one proton for each electron in the entire atom so that the net positive charge of the nucleus is balanced by the net negative charge of the electrons whirling around the nucleus. THUS THE ATOM IS ELECTRICALLY NEUTRAL.

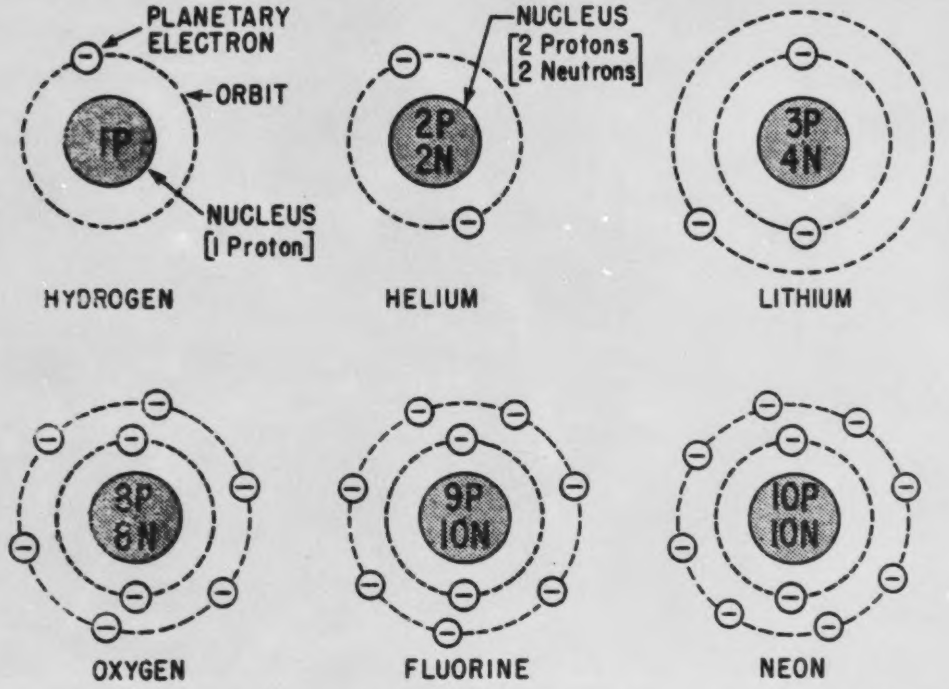
The electons do not fall into the nucleus even though they are attracted strongly to it. Their motion prevents it, as the planets are prevented from falling into the sun because of their centrifugal force of revolution.

The number of protons, which is usually the same as the number of electrons, determines the kind of element in question. Figure 2-2 shows a simplified picture of several atoms of different materials based on the conception of planetary electrons describing orbits about the nucleus. For example, hydrogen has a nucleus consisting of 1 proton, around which rotates 1 electron. The helium atom has a nucleus containing 2 protons and 2 neutrons with 2 electrons encircling the nucleus. Near the other extreme of the list of elements is curium (not shown in the figure), an element discovered in the 1940's, which has 96 protons and 96 electrons in each atom.

The Periodic Table of the Elements is an orderly arrangement of the elements in ascending atomic number (number of planetary electrons) and also in atomic weight (number of protons and neutrons in the nucleus). The various kinds of atoms have distinct masses or weights with respect to each other. The element most closely approaching unity (meaning 1) is hydrogen whose atomic weight is 1.008 as compared with oxygen whose atomic weight is 16. Helium has an atomic weight of approximately 4, lithium 7, fluorine 19, and neon 20, as shown in figure 2-2.

Figure 2-3 is a pictorial summation of the discussion that has just been presented. Visible matter, at the left of the figure, is broken down first to one of its basic molecules, then to one of the molecule's atoms. The atom is then further reduced to its subatomic particles—the protons, neutrons, and electrons. Subatomic particles are electric in nature. That is, they are the particles of matter most affected by an electric force. Whereas the whole molecule or a whole atom is electrically neutral, most subatomic particles are not neutral (with the exception of the neutron). Protons are inherently positive, and electrons are inherently negative. It is these inherent characteristics which make subatomic particles sensitive to electric force.

When an electric force is applied to a conducting medium, such as copper wire, electrons in the outer orbits of the copper atoms are forced



BE.3

Figure 2-2.—Atomic structure of elements.

out of orbit and impelled along the wire. The direction of electron movement is determined by the direction of the impelling force. The protons do not move, mainly because they are extremely heavy. The proton of the lightest element, hydrogen, is approximately 1,850 times heavier than its electron. Thus, it is the relatively light electron that is moved by electricity.

When an orbital electron is removed from an atom it is called a FREE ELECTRON. Some of the electrons of certain metallic atoms are so loosely bound to the nucleus that they are comparatively free to move from atom to atom. Thus, a very small force or amount of energy will cause such electrons to be removed from the atom and become free electrons. It is these free electrons that constitute the flow of an electric current in electrical conductors.

If the internal energy of an atom is raised above its normal state, the atom is said to be EXCITED. Excitation may be produced by causing the atoms to collide with particles that are impelled by an electric force. In this way, energy is transferred from the electric source to the atom. The excess energy absorbed by an atom may become sufficient to cause loosely bound outer electrons to leave the atom against the force that acts to hold them within. An atom that has thus lost or gained one or more electrons is said to be IONIZED. If the atom loses electrons it becomes positively charged and is referred to as a POSITIVE ION. Conversely, if the atom gains electrons, it becomes negatively charged and is referred to as a NEGATIVE ION. An ion may then be defined as a small particle of matter having a positive or negative charge.

CONDUCTORS, SEMICONDUCTORS, AND INSULATORS

Substances that permit the free motion of a large number of electrons are called CONDUCTORS. Copper wire is considered a good conductor because it has many free electrons. Electrical energy is transferred through conductors by means of the movement of free electrons that migrate from atom to atom inside the conductor. Each electron moves a very short distance to the neighboring atom where it replaces one or more electrons by forcing them out of their orbits. The replaced electrons repeat the process in other nearby atoms until the

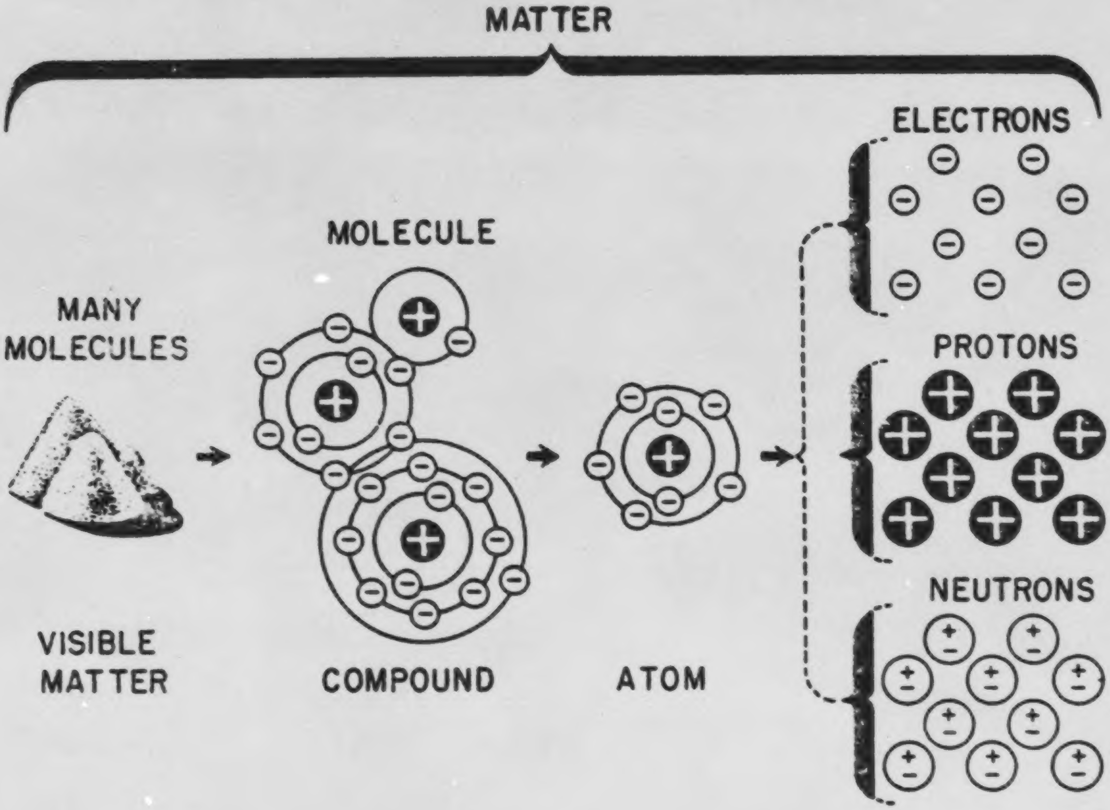


Figure 2-3.—Breakdown of visible matter to electric particles.

movement is transmitted throughout the entire length of the conductor. The greater the number of electrons that can be made to move in a material under the application of a given force the better are the conductive qualities of that material. A good conductor is said to have a low opposition or low resistance to the current (electron) flow. Among the most commonly known metals used as conductors are silver, copper, and aluminum. The best conductor is silver, copper, and aluminum, in that order. However, copper is used more extensively because it is less expensive. A material's ability to conduct electricity also depends on its dimensions.

In contrast to good conductors, some substances such as rubber, glass, and dry wood have very few free electrons. In these materials large amounts of energy must be expended in order to break the electrons loose from the influence of the nucleus. Substances containing very few free electrons are called POOR CONDUCTORS, NONCONDUCTORS, or INSULATORS. Actually, there is no sharp dividing line between conductors and insulators, since electron motion is known to exist to some extent in all matter. Electricians simply use the best conductors as wires to carry current and the poorest conductors as insulators to prevent the current from being diverted from the wires.

Listed below are some of the best conductors and best insulators arranged in accordance with their respective abilities to conduct or to resist the flow of electrons.

Conductors	Insulators
Silver	Dry air
Copper	Glass
Aluminum	Mica
Zinc	Rubber
Brass	Asbestos
Iron	Bakelite

A semiconductor is a material that is neither a good conductor nor a good insulator. Germanium and silicon are substances that fall into this category. These materials, due to their peculiar crystalline structure, may under certain conditions act as conductors; under other conditions, as insulators. As the temperature is raised, however, a limited number of electrons become available for conduction.

STATIC ELECTRICITY

In a natural, or neutral state, each atom in a body of matter will have the proper number of electrons in orbit around it. Consequently, the whole body of matter comprised of the neutral atoms will also be electrically neutral. In this state, it is said to have a "zero charge," and will neither attract nor repel other matter in its vicinity. Electrons will neither leave nor enter the neutrally charged body should it come in contact with other neutral bodies. If, however, any number of electrons are removed from the atoms of a body of matter, there will remain more protons than electrons, and the whole body of matter will become electrically positive. Should the positively charged body come in contact with another body having a normal charge, or having a negative (too many electrons) charge, an electric current will flow between them. Electrons will leave the more negative body and enter the positive body. This electron flow will continue until both bodies have equal charges.

When two bodies of matter have unequal charges, and are near one another, an electric force is exerted between them because of their unequal charges. However, since they are not in contact, their charges cannot equalize. The existence of such an electric force, where current cannot flow, is referred to as static electricity. "Static" means "not moving." This is also referred to as an ELECTROSTATIC FORCE.

One of the easiest ways to create a static charge is by the friction method. With the friction method, two pieces of matter are rubbed together and electrons are "wiped off" one onto the other. If materials that are good conductors are used, it is quite difficult to obtain a detectable charge on either. The reason for this is that equalizing currents will flow easily in and between the conducting materials. These currents equalize the charges almost as fast as they are created. A static charge is easier to obtain by rubbing a hard nonconducting material against a soft, or fluffy, nonconductor. Electrons are rubbed off one material and onto the other material. This is illustrated in figure 2-4.

When the hard rubber rod is rubbed in the fur, the rod accumulates electrons. Since both fur and rubber are poor conductors, little equalizing current can flow, and an electrostatic charge is built up. When the charge is great enough, equalizing currents will flow regardless of the material's poor conductivity. These currents will cause visible sparks, if viewed in darkness, and produce a cracking sound.

CHARGED BODIES

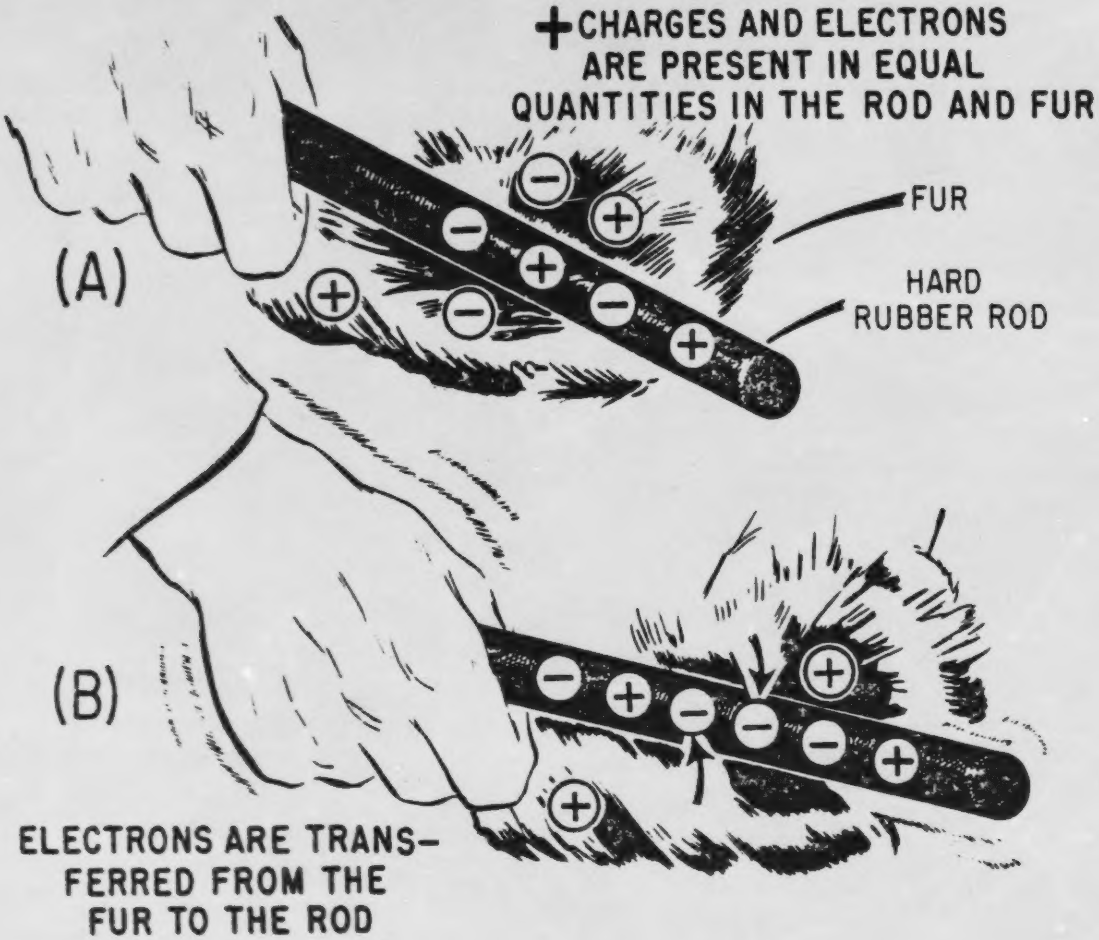
One of the fundamental laws of electricity is that LIKE CHARGES REPEL EACH OTHER and UNLIKE CHARGES ATTRACT EACH OTHER. A positive charge and negative charge, being unlike, tend to move toward each other. In the atom the negative electrons are drawn toward the positive protons in the nucleus. This attractive force is balanced by the electron's centrifugal force caused by its rotation about the nucleus. As a result, the electrons remain in orbit and are not drawn into the nucleus. Electrons repel each other because of their like negative charges, and protons repel each other because of their like positive charges.

The law of charged bodies may be demonstrated by a simple experiment. Two pith (paper pulp) balls are suspended near one another by threads, as shown in figure 2-5.

If the hard rubber rod is rubbed to give it a negative charge, and then held against the right-hand ball in part (A), the rod will impart a negative charge to the ball. The right-hand ball will be charged negative with respect to the left-hand ball. When released, the two balls will be drawn together, as shown in figure 2-5 (A). They will touch and remain in contact until the left-hand ball acquires a portion of the negative charge of the right-hand ball, at which time they will swing apart as shown in figure 2-5 (C). If, positive charges are placed on both balls (fig. 2-5 (B)), the balls will also be repelled from each other.

COULOMB'S LAW OF CHARGES

The amount of attracting or repelling force which acts between two electrically charged bodies in free space depends on two things—(1) their charges, and (2) the distance between them. The relationship of charge and distance to


+ CHARGES AND ELECTRONS ARE PRESENT IN EQUAL QUANTITIES IN THE ROD AND FUR
FUR
HARD RUBBER ROD
(A)
(B)
ELECTRONS ARE TRANSFERRED FROM THE FUR TO THE ROD

BE.5

Figure 2-4.—Producing static electricity by friction.

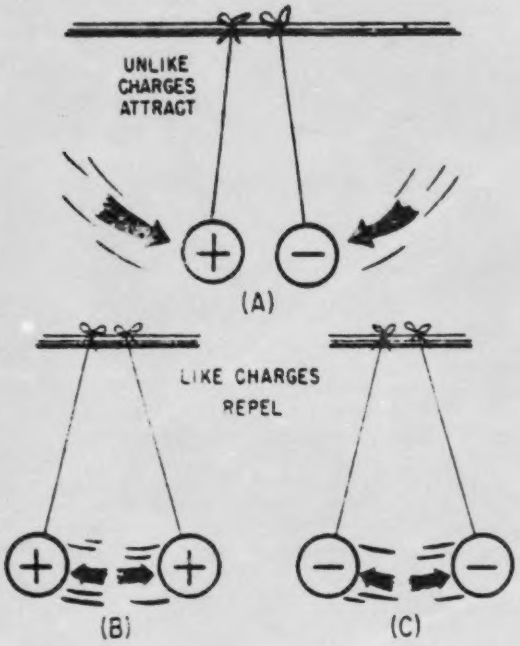
electrostatic force was first discovered and written by a French scientist named Charles A. Coulomb. Coulomb's Law states that CHARGED BODIES ATTRACT OR REPEL EACH OTHER WITH A FORCE THAT IS DIRECTLY PROPORTIONAL TO THE PRODUCT OF THEIR CHARGES, AND IS INVERSELY PROPORTIONAL TO THE SQUARE OF THE DISTANCE BETWEEN THEM.

ELECTRIC FIELDS

The space between and around charged bodies in which their influence is felt is called an ELECTRIC FIELD OF FORCE. The electric field is always terminated on material objects and extends between positive and negative charges. It can exist in air, glass, paper, or a vacuum. ELECTROSTATIC FIELDS and DIELECTRIC FIELDS are other names used to refer to this region of force.

Fields of force spread out in the space surrounding their point of origin and, in general, DIMINISH IN PROPORTION TO THE SQUARE OF THE DISTANCE FROM THEIR SOURCE.

The field about a charged body is generally represented by lines which are referred to as ELECTROSTATIC LINES OF FORCE. These lines are imaginary and are used merely to represent the direction and strength of the field. To avoid confusion, the lines of force exerted by a positive charge are always shown leaving the



BE.6

Figure 2-5.—Reaction between charged bodies.

charge, and for a negative charge they are shown as entering. Figure 2-6 illustrates the use of lines to represent the field about charged bodies.

Figure 2-6 (A) represents the repulsion of like-charged bodies and their associated fields. Part (B) represents the attraction between unlike-charged bodies and their associated fields.

MAGNETISM

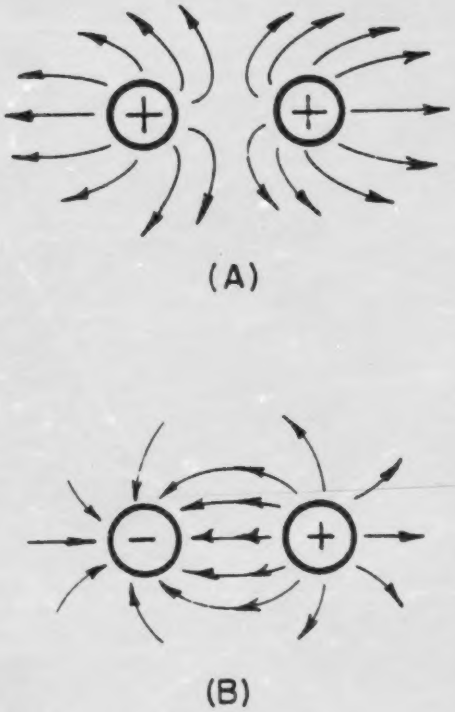
A substance is said to be a magnet if it has the property of magnetism—that is, if it has the power to attract such substances as iron, steel, nickel, or cobalt, which are known as MAGNETIC MATERIALS. A steel knitting needle, magnetized by a method to be described later, exhibits two points of maximum attraction (one at each end) and no attraction at its center. The points of maximum attraction are called MAGNETIC POLES. All magnets have at least two poles. If the needle is suspended by its middle so that it rotates freely in a horizontal plane about its center, the needle comes to rest in a approximately north-south line of direction. The same pole will always point to the north, and the other will always point toward the south. The magnetic pole that points northward is called the NORTH POLE, and the other the SOUTH POLE.

A MAGNETIC FIELD exists around a simple bar magnet. The field consists of imaginary lines along which a MAGNETIC FORCE acts. These lines emanate from the north pole of the magnet, and enter the south pole, returning to the north pole through the magnet itself, thus forming closed loops.

A MAGNETIC CIRCUIT is a complete path through which magnetic lines of force may be established under the influence of a magnetizing force. Most magnetic circuits are composed largely of magnetic materials in order to contain the magnetic flux. These circuits are similar to the ELECTRIC CIRCUIT, which is a complete path through which current is caused to flow under the influence of an electromotive force.

Magnets may be conveniently divided into three groups.

1. NATURAL MAGNETS, found in the natural state in the form of a mineral called magnetite.



BE.7

Figure 2-6.—Electrostatic lines of force.

2. **PERMANENT MAGNETS, bars of hardened steel (or some form of alloy such as alnico) that have been permanently magnetized.**

3. ELECTROMAGNETS, composed of soft-iron cores around which are wound coils of insulated wire. When an electric current flows through the coil, the core becomes magnetized. When the current ceases to flow, the core loses most of its magnetism.

Permanent magnets and electromagnets are sometimes called ARTIFICIAL MAGNETS to further distinguish them from natural magnets, and are discussed in this manual under the heading of "Artificial Magnets."

NATURAL MAGNETS

For many centuries it has been known that certain stones (magnetite, Fe_3O_4) have the ability to attract small pieces of iron. Because many of the best of these stones (natural magnets) were found near Magnesia in Asia Minor, the Greeks called the substance MAGNETITE, or MAGNETIC.

Before this, ancient Chinese observed that when similar stones were suspended freely, or floated on a light substance in a container of water, they tended to assume a nearly north-and-south position. Probably Chinese navigators used bits of magnetite floating on wood in a liquid-filled vessel as crude compasses. At that time it was not known that the earth itself acts like a magnet, and these stones were regarded with considerable superstitious awe. Because bits of this substance were used as compasses they were called LOADSTONES (or lodestones), which means "leading stones."

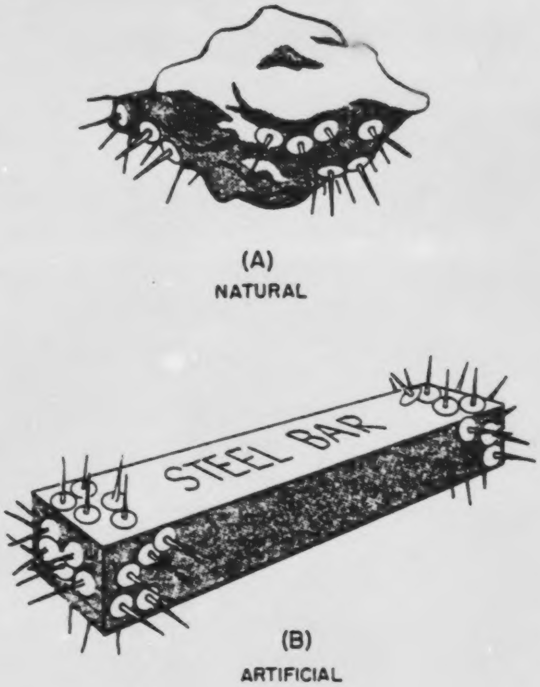
Natural magnets are also found in the United States, Norway, and Sweden. A natural magnet, demonstrating the attractive force at the poles, is shown in figure 2-7 (A).

ARTIFICIAL MAGNETS

Natural magnets no longer have any practical value because more powerful and more conveniently shaped permanent magnets can be produced artificially. Commercial magnets are made from special steels and alloys—for example, alnico, made principally of aluminum, nickel, and cobalt. The name is derived from the first two letters of the three principal elements of which it is composed. An artificial magnet is shown in figure 2-7 (B).

An iron, steel, or alloy bar can be magnetized by inserting the bar into a coil of insulated wire and passing a heavy direct current through the coil, as shown in figure 2-8 (A). This aspect of magnetism is treated later in the chapter. The same bar may also be magnetized if it is stroked with a bar magnet, as shown in figure 2-8 (B). It will then have the same magnetic property that the magnet used to induce the magnetism has—namely, there will be two poles of attraction, one at either end. This process produces a permanent magnet by INDUCTION—that is, the magnetism is induced in the bar by the influence of the stroking magnet.

Artificial magnets may be classified as "permanent" or "temporary" depending on their ability to retain their magnetic strength after the magnetizing force has been removed. Hardened steel and certain alloys are relatively difficult to magnetize and are said to have a LOW PERMEABILITY because the magnetic lines of force do not easily permeate, or distribute themselves readily through the steel. (Permeability is a measure of the relative ability of a substance to conduct magnetic lines of force as compared with

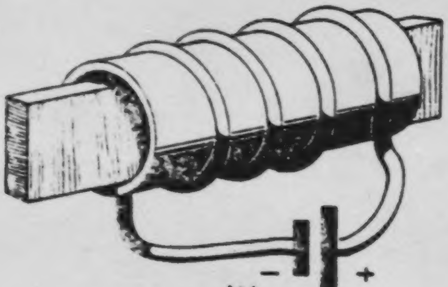


(A)
NATURAL

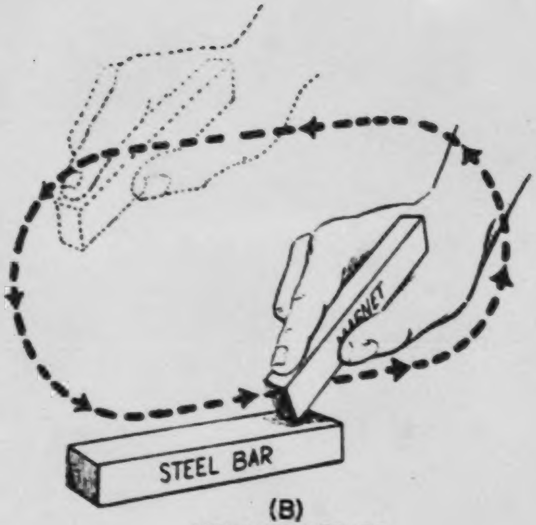
(B)
ARTIFICIAL

BE.8

Figure 2-7.—(A) Natural magnet; (B) artificial magnet.



(A)
COIL METHOD



(B)
STROKING METHOD

BE.9

Figure 2-8.—Methods of producing artificial magnets.

air. It is discussed in greater detail later in this manual.) Once magnetized, however, these materials retain a large part of their magnetic strength and are called PERMANENT MAGNETS. Permanent magnets are used extensively in electric instruments, meters, telephone receivers, permanent-magnet loudspeakers, and magnetos. Conversely, substances that are relatively easy to magnetize—such as soft iron and annealed silicon steel—are said to have a HIGH PERMEABILITY. Such substances retain only a small part of their magnetism after the magnetizing force is removed and are called TEMPORARY MAGNETS. Silicon steel and similar materials are used in transformers where the magnetism is constantly changing and in generators and motors where the strength of the fields can be readily changed.

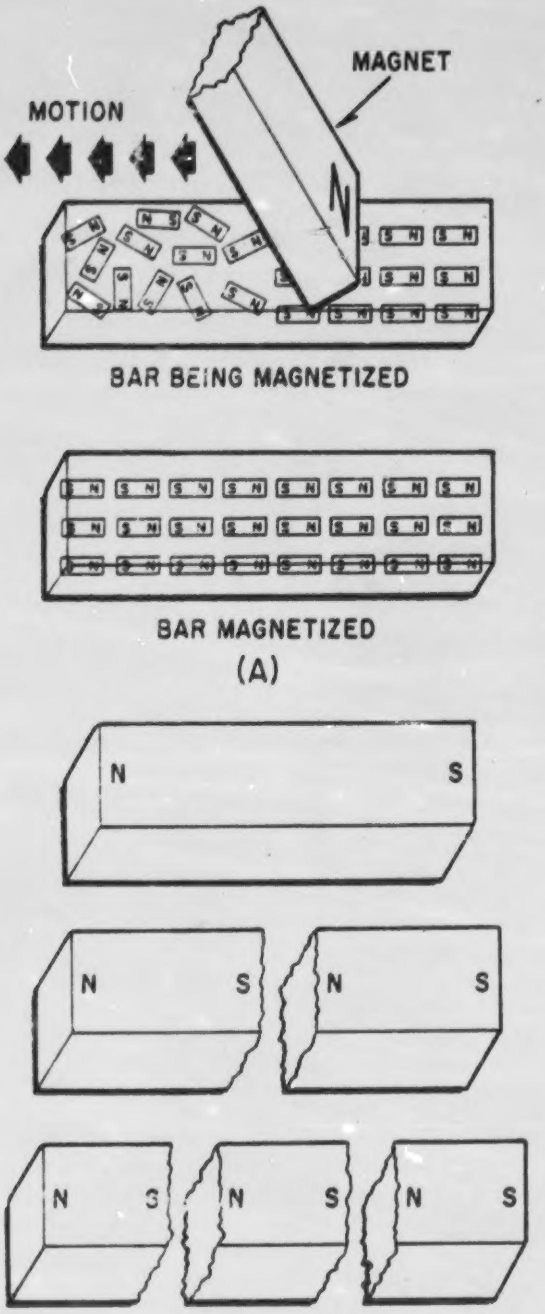
The magnetism that remains in a temporary magnet after the magnetizing force is removed is called RESIDUAL MAGNETISM. The fact that temporary magnets retain even a small amount of magnetism is an important factor in the build-up of voltage in self-excited d-c generators.

NATURE OF MAGNETISM

A popular theory of magnetism considers the molecular alinement of the material. This is known as Weber's Theory. This theory assumes all magnetic substances to be composed of tiny molecular magnets. All unmagnetized materials have the magnetic forces of its molecular magnets neutralized by adjacent molecular magnets thereby eliminating any magnetic effect. A magnetized material will have most of its molecular magnets lined up so that the north pole of each molecule points in one direction, and the south pole faces the opposite direction. A material with its molecules thus alined will then have one effective north pole, and one effective south pole. An illustration of Weber's Theory is shown in figure 2-9 (A) where a steel bar is magnetized by stroking. When a steel bar is stroked several times in the same direction by a magnet, the magnetic force from the north pole of the magnet causes the molecules to aline themselves. The polarity of the magnet formed is dependent upon the direction of the magnetizing force as it is brought over the random magnetic molecules.

Some justification of Weber's Theory occurs when a magnet is split in half. It is found that each half possess both a north and a south magnetic pole as shown in figure 2-9 (B). The polarities of the poles are in the same respective directions as the poles of the original magnet. If a magnet is further divided into small parts, it will be found that each part, down to its last molecule, will all have similar north and south poles. Each part would exhibit its own magnetic properties.

Further support of Weber's Theory comes from the fact that when a bar magnet is held out of alinement with the earth's magnetic field and repeatedly jarred or heated, the molecular alinement is disarranged and the material becomes demagnetized. For example, measuring devices which make use of permanent magnets become inaccurate when subjected to severe jarring or exposure to opposing magnetic fields.



BE.10

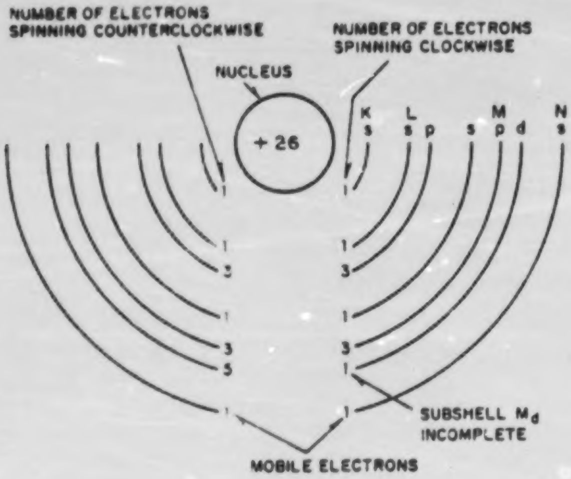
Figure 2-9.—(A) Molecular magnets; (B) broken magnets.

DOMAIN THEORY

A more modern theory of magnetism is based on the electron spin principle. From the study of atomic structure it is known that all matter is composed of vast quantities of atoms, each atom containing one or more orbital electrons. The electrons are considered to orbit in various shells and subshells depending upon their distance from the nucleus. The structure of the atom has previously been compared to the solar system, wherein the electrons orbiting the nucleus correspond to the planets orbiting the sun. Along with their orbital motion about the sun, these planets also revolve on their axes. It is believed that the electron also revolves on its axis as it orbits the nucleus of an atom.

It has been experimentally proven that an electron has a magnetic field about it along with an electric field. The effectiveness of the magnetic field of an atom is determined by the number of electrons spinning in each direction. If an atom has equal numbers of electrons spinning in opposite directions, the magnetic fields surrounding the electrons cancel one another, and the atom is unmagnetized. However, if more electrons spin in one direction than another, the atom is magnetized. An atom such as iron with an atomic number of 26 has 26 protons in the nucleus and 26 revolving electrons orbiting its nucleus. If 13 electrons are spinning in a clockwise direction and 13 electrons are spinning in a counterclockwise direction, the opposing magnetic fields will be neutralized. When more than 13 electrons spin in either direction, the atom is magnetized. An example of a magnetized atom of iron is shown in figure 2-10. Note that in this specific illustration the electrons magnetic fields in all except the M shell neutralize each other. As illustrated in the diagram, there exists 15 electrons spinning in one direction and only 11 electrons spinning in an opposite direction. Therefore, the unopposed magnetic fields of 4 electrons will cause this iron atom to become an infinitely small magnet.

When a number of such atoms are grouped together to form an iron bar, there is an interaction between the magnetic forces of various atoms. The small magnetic force of the field surrounding an atom affects adjacent atoms, thus producing a small group of atoms with parallel magnetic fields. This group of from 10^{14} to 10^{15} magnetic atoms, having their magnetic poles orientated in the same direction, is known as a DOMAIN. Throughout a domain


NUMBER OF ELECTRONS SPINNING COUNTERCLOCKWISE
NUMBER OF ELECTRONS SPINNING CLOCKWISE
NUCLEUS
+26
K
L
M
N
s
s p
s p d
s
1
1
3
1
3
5
1
1
1
3
1
3
1
1
SUBSHELL M_d INCOMPLETE
MOBILE ELECTRONS

BE.11

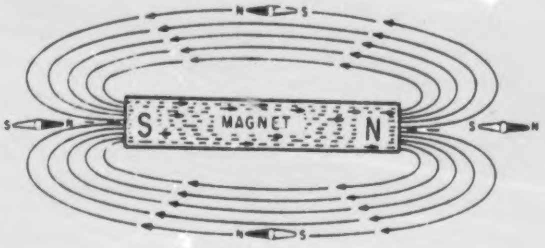
Figure 2-10.—Iron atom.

there is an intense magnetic field without the influence of any external magnetic field. Since about 10 million tiny domains can be contained in 1 cubic millimeter, it is apparent that every magnetic material is made up of a large number of domains. The domains in any substance are always magnetized to saturation but are randomly orientated throughout a material. Thus, the strong magnetic field of each domain is neutralized by opposing magnetic forces of other domains. When an external field is applied to a magnetic substance the domains will line up with the external field. Since the domains themselves are naturally magnetized to saturation, the magnetic strength of a magnetized material is determined by the number of domains alined by the magnetizing force.

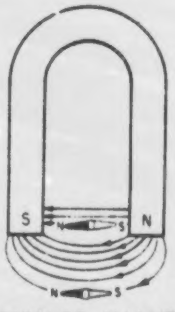
MAGNETIC FIELDS AND LINES OF FORCE

If a bar magnet is dipped into iron filings, many of the filings are attracted to the ends of the magnet, but none are attracted to the center of the magnet. As mentioned previously, the ends of the magnet where the attractive force is the greatest are called the POLES of the magnet. By using a compass, the line of direction of the magnetic force at various points near the magnet may be observed. The compass needle itself is a magnet. The north end of the compass needle always points toward the south pole, S, as shown in figure 2-11 (A), and thus the sense of direction (with respect to the polarity of the bar magnet) is also indicated. At the center, the compass needle points in a direction that is parallel to the bar magnet.

When the compass is placed successively at several points in the vicinity of the bar magnet the compass needle alines itself with the field at each position. The direction of the field is indicated by the arrows and represents the direction in which the north pole of the compass needle will point when the compass is placed in this field. Such a line along which a compass needle alines itself is called a MAGNETIC LINE OF FORCE. (This magnetic line of force does not actually exist but is an imaginary line used to illustrate and describe the pattern of the magnetic field. As mentioned previously, the magnetic lines of force are assumed to emanate from the north pole of a magnet, pass through the surrounding space, and enter the south pole. The lines of force then pass from the south pole to the north pole inside the magnet to form a closed loop. Each line of force forms an independent closed loop and does not merge with or cross other lines of force. The lines of force between the poles of a horseshoe magnet are shown in figure 2-11 (B).



BAR MAGNET
(A)



HORSESHOE MAGNET
(B)

BE.12

Figure 2-11.—Magnetic lines of force.

Although magnetic lines of force are imaginary, a simplified version of many magnetic phenomena can be explained by assuming the magnetic lines to have certain real properties. The lines of force can be compared to rubberbands which stretch outward when a force is exerted upon them and contract when the force is removed. The characteristics of magnetic lines of force can be described as follows:

1. Magnetic lines of force are continuous and will always form closed loops.
2. Magnetic lines of force will never cross one another.
3. Parallel magnetic lines of force traveling in the same direction repel one another. Parallel magnetic lines of force traveling in opposite directions tend to unite with each other and form into single lines traveling in a direction determined by the magnetic poles creating the lines of force.
4. Magnetic lines of force tend to shorten themselves. Therefore, the magnetic lines of force existing between two unlike poles cause the poles to be pulled together.
5. Magnetic lines of force pass through all materials, both magnetic and nonmagnetic.

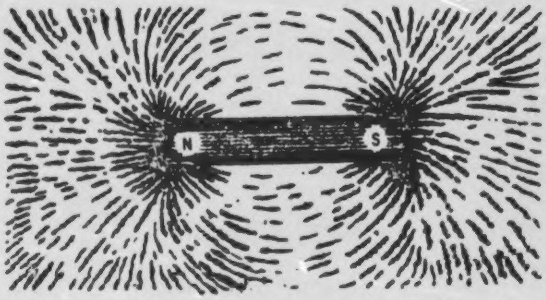
The space surrounding a magnet, in which the magnetic force acts, is called a MAGNETIC FIELD. Michael Faraday was the first scientist to visualize the magnet field as being in a state of stress and consisting of uniformly distributed lines of force. The entire quantity of magnetic lines surrounding a magnet is called MAGNETIC FLUX. Flux in a magnetic circuit corresponds to current in an electric circuit.

The number of lines of force per unit area is called FLUX DENSITY and is measured in lines per square inch or lines per square centimeter. Flux density is expressed by the equation

$$B = \frac{\Phi}{A},$$

where B is the flux density, Φ (Greek phi) is the total number of lines of flux, and A is the cross-sectional area of the magnetic circuit. If A is in square centimeters, B is in lines per square centimeter, or GAUSS. The terms FLUX and FLOW of magnetism are frequently used in textbooks. However, magnetism itself is not thought to be a stream of particles in motion, but is simply a field of force exerted in space.

A visual representation of the magnetic field around a magnet can be obtained by placing a plate of glass over a magnet and sprinkling iron filings onto the glass. The filings arrange themselves in definite paths between the poles. This arrangement of the filings shows the pattern of the magnetic field around the magnet, as in figure 2-12.



BE.13

Figure 2-12.—Magnetic field pattern around a magnet.

The magnetic field surrounding a symmetrically shaped magnet has the following properties:

1. The field is symmetrical unless disturbed by another magnetic substance.
2. The lines of force have direction and are represented as emanating from the north pole and entering the south pole.

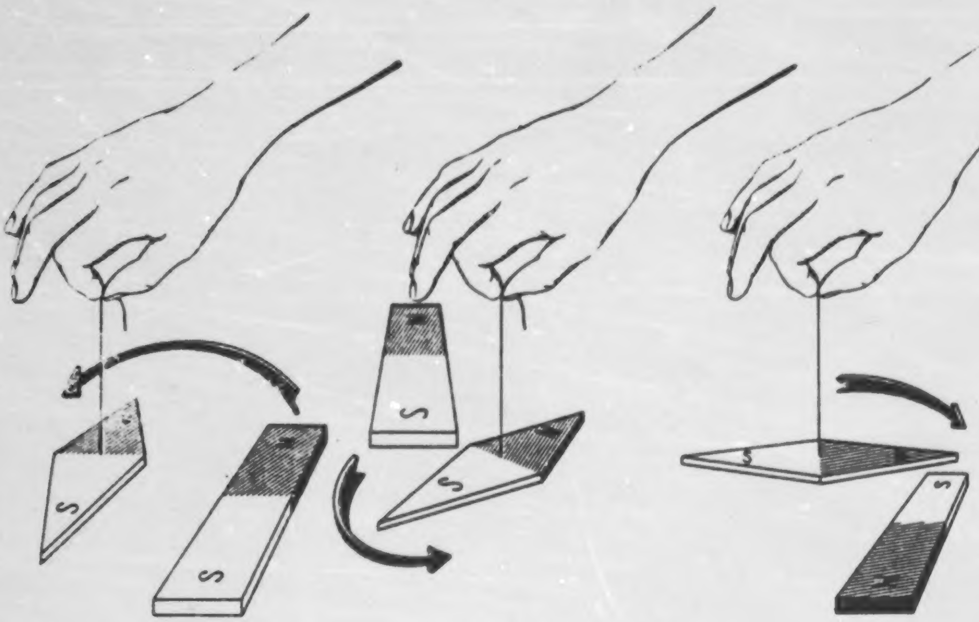
LAWS OF ATTRACTION AND REPULSION

If a magnetized needle is suspended near a bar magnet, as in figure 2-13, it will be seen that a north pole repels a north pole and a south pole repels a south pole. Opposite poles, however, will attract each other. Thus, the first two laws of magnetic attraction and repulsion are:

1. LIKE magnetic poles REPEL each other.
2. UNLIKE magnetic poles ATTRACT each other.

The flux patterns between adjacent UNLIKE poles of bar magnets, as indicated by lines, are shown in figure 2-14 (A). Similar patterns for adjacent LIKE poles are shown in figure 2-14 (B). The lines do not cross at any point and they act as if they repel each other.

Figure 2-15 shows the flux pattern (indicated by lines) around two bar magnets placed close together and parallel with each other. Figure 2-15 (A) shows the flux pattern when opposite



REPULSION REPULSION ATTRACTION

BE.14

Figure 2-13.—Laws of attraction and repulsion.

poles are adjacent; and figure 2-15 (B) shows the flux pattern when like poles are adjacent.

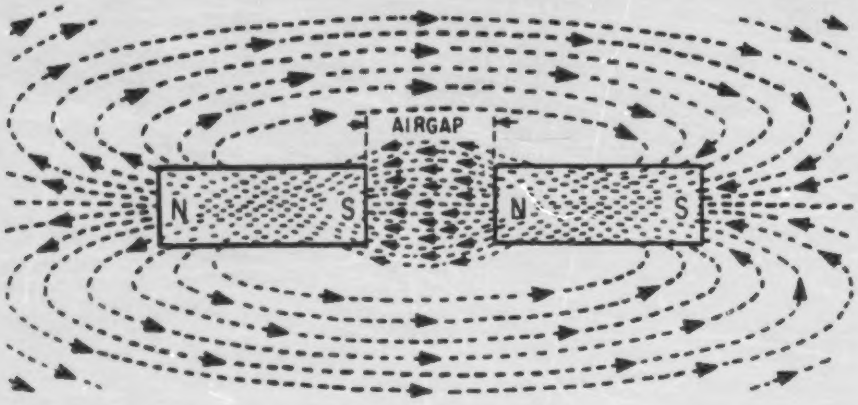
The THIRD LAW of magnetic attraction and repulsion states in effect that the force of attraction or repulsion existing between two magnetic poles decreases rapidly as the poles are separated from each other. Actually, the force of attraction or repulsion varies directly as the product of the separate pole strengths and inversely as the square of the distance separating the magnetic poles, provided the poles are small enough to be considered as points. For example, if the distance between two north poles is increased from 2 feet to 4 feet, the force of repulsion between them is decreased to one-fourth of its original value. If either pole strength is doubled, the distance remaining the same, the force between the poles will be doubled.

THE EARTH'S MAGNETISM

As has been stated, the earth is a huge magnet; and surrounding the earth is the magnetic field produced by the earth's magnetism. The magnetic polarities of the earth are as indicated in figure 2-16. The geographic poles are also shown at each end of the axis of rotation of the earth. The magnetic axis does not coincide with the geographic axis, and therefore the magnetic and geographic poles are not at the same place on the surface of the earth.

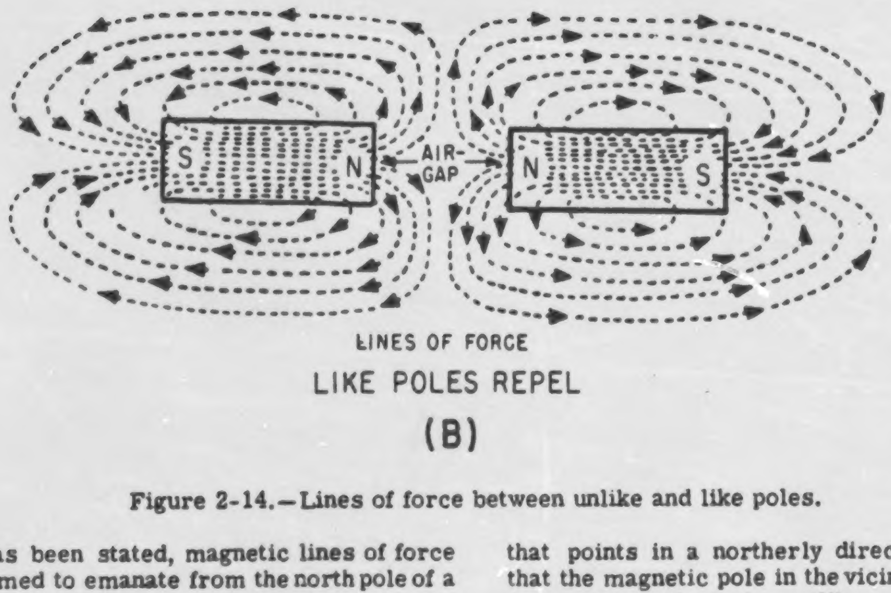
The early users of the compass regarded the end of the compass needle that points in a northerly direction as being a north pole. The other end was regarded as a south pole. On some maps the magnetic pole of the earth towards which the north pole of the compass pointed was designated a north magnetic pole. This magnetic pole was obviously called a north pole because of its proximity to the north geographic pole.

When it was learned that the earth is a magnet and that opposite poles attract, it was necessary to call the magnetic pole located in the northern hemisphere a SOUTH MAGNETIC POLE and the magnetic pole located in the southern hemisphere a NORTH MAGNETIC POLE. The matter of naming the poles was arbitrary. Therefore, the polarity of the compass needle that points toward the north must be opposite to the polarity of the earth's magnetic pole located there.



UNLIKE POLES ATTRACT

(A)



LIKE POLES REPEL

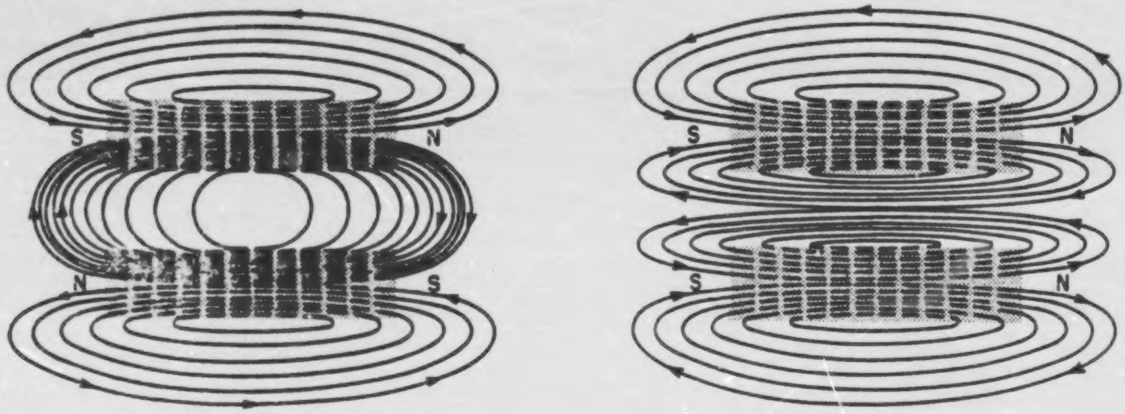
(B)

BE.15

Figure 2-14.—Lines of force between unlike and like poles.

As has been stated, magnetic lines of force are assumed to emanate from the north pole of a magnet and to enter the south pole as closed loops. Because the earth is a magnet, lines of force emanate from its north magnetic pole and enter the south magnetic pole as closed loops. The compass needle alines itself in such a way that the earth's lines of force enter at its south pole and leave at its north pole. Because the north pole of the needle is defined as the end that points in a northerly direction it follows that the magnetic pole in the vicinity of the north geographic pole is in reality a south magnetic pole, and vice versa.

Because the magnetic poles and the geographic poles do not coincide, a compass will not (except at certain positions on the earth) point in a true (geographic) north-south direction—that is, it will not point in a line of direction that passes through the north and south



FLUX PATTERN—ATTRACTION
(A)

FLUX PATTERN—REPULSION
(B)

BE.16

Figure 2-15.—Flux patterns of adjacent parallel bar magnets.

geographic poles, but in a line of direction that makes an angle with it. This angle is called the angle of VARIATION OR DECLINATION.

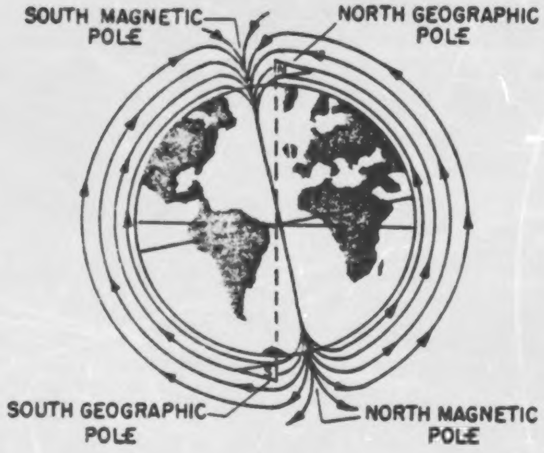


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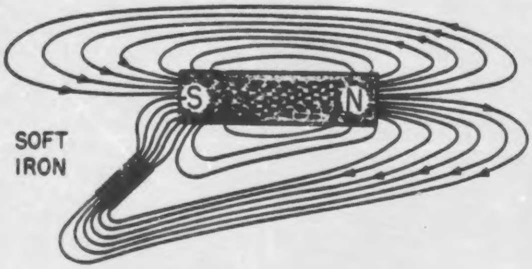
Figure 2-16.—Earth's magnetic poles.

MAGNETIC SHIELDING

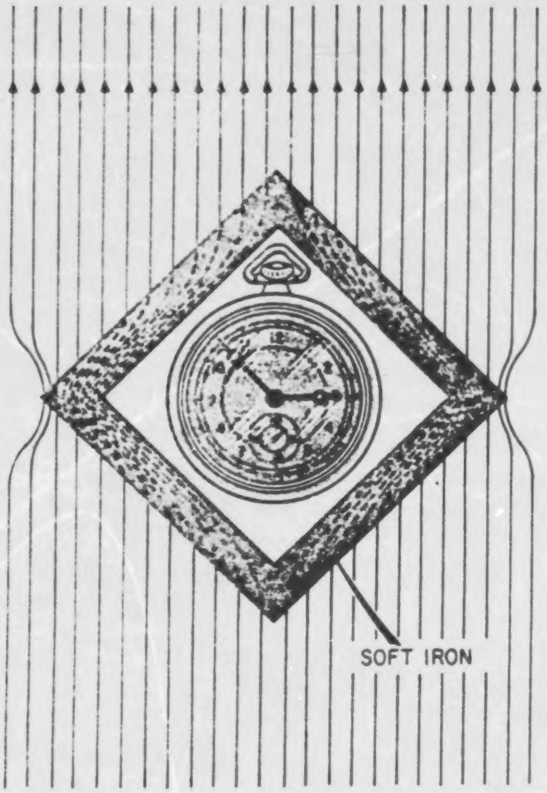
There is not a known INSULATOR for magnetic flux. If a nonmagnetic material is placed in a magnetic field, there is no appreciable change in flux—that is, the flux penetrates the nonmagnetic material. For example, a glass plate placed between the poles of a horseshoe magnet will have no appreciable effect on the field although glass itself is a good insulator in an electric circuit. If a magnetic material (for example, soft iron) is placed in a magnetic field, the flux may be redirected to take advantage of the greater permeability of the magnetic material as shown in figure 2-17. Permeability, as discussed earlier, is the quality of a substance which determines the ease with which it can be magnetized.



BE.18

Figure 2-17.—Effects of a magnetic substance in a magnetic field.

The sensitive mechanism of electric instruments and meters can be influenced by stray magnetic fields which will cause errors in their readings. Because instrument mechanisms cannot be insulated against magnetic flux, it is necessary to employ some means of directing the flux around the instrument. This is accomplished by placing a soft-iron case, called a MAGNETIC SCREEN OR SHIELD, about the instrument. Because the flux is established more readily through the iron (even though the path is longer) than through the air inside the case, the instrument is effectively shielded, as shown by the watch and soft-iron shield in figure 2-18.



BE.19

Figure 2-18.—Magnetic shield.

MAGNETIC MATERIALS

Early magnetic studies classified materials merely as being magnetic and nonmagnetic. Present studies classify materials into one of three groups; namely, paramagnetic, diamagnetic, and ferromagnetic.

PARAMAGNETIC materials are those that become only slightly magnetized even though under the influence of a strong magnetic field. This slight magnetization is in the same direction as the magnetizing field. Materials of this type are aluminum, chromium, platinum, and air.

DIAMAGNETIC materials can also be only slightly magnetized when under the influence of a very strong field. These materials, when slightly magnetized, are magnetized in a direction opposite to the external field. Some diamagnetic materials are copper, silver, gold, and mercury.

Paramagnetic and diamagnetic materials have a very low permeability. Paramagnetic materials have a permeability slightly greater than one; diamagnetic materials have a permeability less than one. Because of the difficulty in obtaining some magnetization of paramagnetic and diamagnetic materials, these materials are considered for all practical purposes as nonmagnetic materials.

The most important group of materials for applications of electricity and electronics are the FERROMAGNETIC MATERIALS. Ferromagnetic materials are those which are relatively easy to magnetize such as iron, steel, cobalt, Alnico, and Permalloy, the latter two being alloys. Alnico consists primarily of aluminum, nickel, and cobalt. These new alloys can be very strongly magnetized with Alnico capable of obtaining a magnetic strength great enough to lift five hundred times its own weight.

Ferromagnetic materials all have a high permeability. However, as previously discussed, a material, such as steel used to make a permanent magnet, is considered to have a relatively low permeability in comparison to other ferromagnetic materials.

MAGNETIC SHAPES

Because of the many uses of magnets, they are found in various shapes and sizes. However, magnets usually come under three general classifications; namely, bar magnets, horseshoe magnets, and ring magnets.

The bar magnet is most often used in schools and laboratories for studying the properties and effects of magnetism. In the preceding test material, the bar magnet proved very helpful in demonstrating magnetic effects.

Another type of magnet is the ring magnet used for computer memory cores. A common application for a temporary ring magnet would be the shielding of electrical instruments as previously discussed.

The shape of the magnet most frequently used in electrical or electronic equipment is called the horseshoe magnet. A horseshoe magnet is similar to a bar magnet but is bent in the shape of a horseshoe. The horseshoe magnet provides much more magnetic strength than a bar magnet of the same size and material because of the closeness of the magnetic poles. The magnetic strength from one pole to the other is greatly increased due to the concentration of the magnetic field in a smaller area. Electrical measuring devices quite frequently use horseshoe type magnets.

CARE OF MAGNETS

A piece of steel that has been magnetized can lose much of its magnetism by improper handling. If it is jarred or heated, there will be a disalinement of its domains resulting in the loss of some of its effective magnetism. Had this steel formed the horseshoe magnet of a meter, the meter would no longer be operable or would give inaccurate readings. Therefore, care must be exercised when handling instruments containing magnets. Severe jarring or subjecting the instrument to high temperature will damage the device.

A magnet may also become weakened from loss of flux. Thus, when storing magnets one should always try to avoid excess leakage of magnetic flux. A horseshoe magnet should always be stored with a keeper, a soft iron bar used to join the magnetic poles. By use of the keeper while the magnet is being stored, the magnetic flux will continuously circulate through the magnet and not leak off into space.

When storing bar magnets, the same principle must be remembered. Therefore, bar magnets should always be stored in pairs with a north pole and a south pole placed together. This provides a complete path for the magnetic flux without any flux leakage.

The study of electricity and magnetism and how they interact with each other is given more thorough coverage in later chapters in this manual. The discussion of magnetism up to this point has been mainly intended to clarify terms and meanings, such as "polarity," "fields," "lines of force," etc. Only one fundamental relationship between magnetism and electricity is discussed in this chapter. This relationship pertains to magnetism as used to generate a voltage and it is discussed in the material that follows.

DIFFERENCE IN POTENTIAL

The force that causes free electrons to move in a conductor as an electric current may be referred to as follows:

1. Electromotive force (emf).
2. Voltage.
3. Difference in potential.

When a difference in potential exists between two charged bodies that are connected by a conductor, electrons will flow along the conductor. This flow is from the negatively charged body to the positively charged body until the two charges are equalized and the potential difference no longer exists.

An analogy of this action is shown in the two water tanks connected by a pipe and valve in figure 2-19. At first the valve is closed and all the water is in tank A. Thus, the water pressure across the valve is at maximum. When the valve is opened, the water flows through the pipe from A to B until the water level becomes the same in both tanks. The water then stops flowing in the pipe, because there is no longer a difference in water pressure between the two tanks.

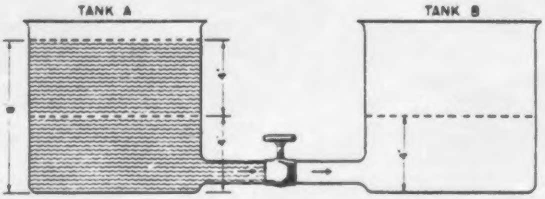


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Figure 2-19.—Water analogy of electric difference in potential.

Current flow through an electric circuit is directly proportional to the difference in potential across the circuit, just as the flow of water through the pipe in figure 2-19 is directly proportional to the difference in water level in the two tanks.

A fundamental law of current electricity is that the CURRENT IS DIRECTLY PROPORTIONAL TO THE APPLIED VOLTAGE; that is, if the voltage is increased, the current is increased. If the voltage is decreased, the current is decreased.

PRIMARY METHODS OF PRODUCING A VOLTAGE

Presently, there are six commonly used methods of producing electromotive force (emf). Some of these methods are much more widely used than others. The following is a list of the six most common methods of producing electromotive force.

1. **FRICTION.**—Voltage produced by rubbing two materials together.
2. PRESSURE (Piezoelectricity).—Voltage produced by squeezing crystals of certain substances.
3. HEAT (Thermoelectricity).—Voltage produced by heating the joint (junction) where two unlike metals are joined.
4. LIGHT (Photoelectricity).—Voltage produced by light striking photosensitive (light sensitive) substances.
5. CHEMICAL ACTION.—Voltage produced by chemical reaction in a battery cell.
6. MAGNETISM.—Voltage produced in a conductor when the conductor moves through a magnetic field, or a magnetic field moves through the conductor in such a manner as to cut the magnetic lines of force of the field.

VOLTAGE PRODUCED BY FRICTION

This is the least used of the six methods of producing voltages. Its main application is in Van de Graf generators, used by some laboratories to produce high voltages. As a rule, friction electricity (often referred to as static electricity) is a nuisance. For instance, a flying aircraft accumulates electric charges from the friction between its skin and the passing air. These charges often interfere with radio communication, and under some circumstances can even cause physical damage to the aircraft. Most individuals are familiar with static electricity and have probably received unpleasant shocks from friction electricity upon sliding across dry seat covers or walking across dry carpets, and then coming in contact with some other object.

VOLTAGE PRODUCED BY PRESSURE

This action is referred to as piezoelectricity. It is produced by compressing or decompressing crystals of certain substances. To study this form of electricity, the meaning of the word "crystal" must first be understood. In a crystal, the molecules are arranged in an orderly and uniform manner. A substance in its crystallized state and its noncrystallized state is shown in figure 2-20.

For the sake of simplicity, assume that the molecules of this particular substance are spherical (ball-shaped). In the noncrystallized state, in (A), note that the molecules are arranged irregularly. In the crystallized state, (B), the molecules are arranged in a regular and uniform manner. This illustrates the major physical difference between crystal and noncrystal forms of matter. Natural crystalline matter is rare; an example of matter that is crystalline in its natural form is diamond, which is crystalline carbon. Most crystals are manufactured.

Crystals of certain substances, such as Rochelle salt or quartz, exhibit peculiar electrical characteristics. These characteristics, or effects, are referred to as "piezoelectric." For instance, when **a crystal of quartz** is

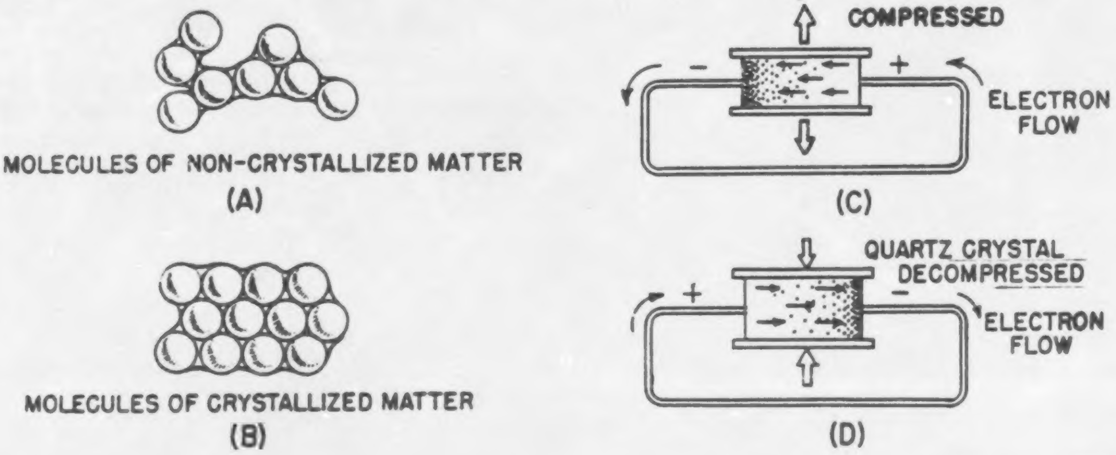

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Figure 2-20.—(A) Noncrystallized structure; (B) crystallized structure; (C) compression of a crystal; (D) decompression of a crystal.

compressed, as in figure 2-20 (C), electrons tend to move through the crystal as shown. This tendency creates an electric difference of potential between the two opposite faces of the crystal. (The fundamental reasons for this action are not known. However, the action is predictable, and therefore useful.) If an external wire is connected while the pressure and emf are present, electrons will flow. If the pressure is held constant, the electron flow will continue until the charges are equalized. When the force is removed, the crystal is decompressed, and immediately causes an electric force in the opposite direction (D). Thus, the crystal is able to convert mechanical force, either pressure or tension, to electrical force.

The power capacity of a crystal is extremely small. However, they are useful because of their extreme sensitivity to changes of mechanical force or changes in temperature. Due to other characteristics not mentioned here, crystals are most widely used in communication equipment.

VOLTAGE PRODUCED BY HEAT

When a length of metal, such as copper, is heated at one end, electrons tend to move away from the hot end toward the cooler end. This is true of most metals. However, in some metals, such as iron, the opposite takes place and electrons tend to move TOWARD the hot end. These characteristics are illustrated in figure 2-21. The negative charges (electrons) are moving through the copper away from the heat and through the iron toward the heat. They cross from the iron to the copper at the hot junction, and from the copper through the current meter to the iron at the cold junction. This device is generally referred to as a thermocouple.

Thermocouples have somewhat greater power capacities than crystals, but their capacity is still very small if compared to some other sources. The thermoelectric voltage in a thermocouple depends mainly on the difference in temperature between the hot and cold junctions. Consequently, they are widely used to measure temperature, and as heat-sensing devices in automatic temperature control equipment. Thermocouples generally can be subjected to much greater temperatures than ordinary thermometers, such as the mercury or alcohol types.

VOLTAGE PRODUCED BY LIGHT

When light strikes the surface of a substance, it may dislodge electrons from their orbits around the surface atoms of the substance. This occurs because light has energy, the same as any moving force.

Some substances, mostly metallic ones, are far more sensitive to light than others. That is, more electrons will be dislodged and emitted from the surface of a highly sensitive metal, with a given amount of light, than will be emitted from a less sensitive substance. Upon losing electrons, the photosensitive (light sensitive) metal becomes positively charged, and an electric force is created. Voltage produced in this manner is referred to as "a photoelectric voltage."

The photosensitive materials most commonly used to produce a photoelectric voltage are various compounds of silver oxide or copper oxide. A complete device which operates on the photoelectric principle is referred to as a "photoelectric cell." There are many sizes and types of photoelectric cells in use, each of which serves the special purpose for which it was designed. Nearly all, however, have some of the basic features of the photoelectric cells shown in figure 2-22.

The cell (fig. 2-22 (A)) has a curved light-sensitive surface focused on the central anode. When light from the direction shown strikes the sensitive surface, it emits electrons toward the anode. The more intense the light, the greater is the number of electrons emitted. When a wire is connected between the filament and the back, or dark side, the accumulated electrons will flow to the dark side. These electrons will eventually pass through the metal of the reflector and replace the electrons leaving the light-sensitive surface. Thus, light energy is converted to a flow of electrons, and a usable current is developed.

The cell (fig. 2-22 (B)) is constructed in layers. A base plate of pure copper is coated with light-sensitive copper oxide. An additional semitransparent layer of metal is placed over the copper oxide. This additional layer serves two purposes:

1. It is EXTREMELY thin to permit the penetration of light to the copper oxide.
2. It also accumulates the electrons emitted by the copper oxide.

An externally connected wire completes the electron path, the same as in the reflector type cell. The photocell's voltage is utilized as needed by connecting the external wires to some other device, which amplifies (enlarges) it to a usable level.

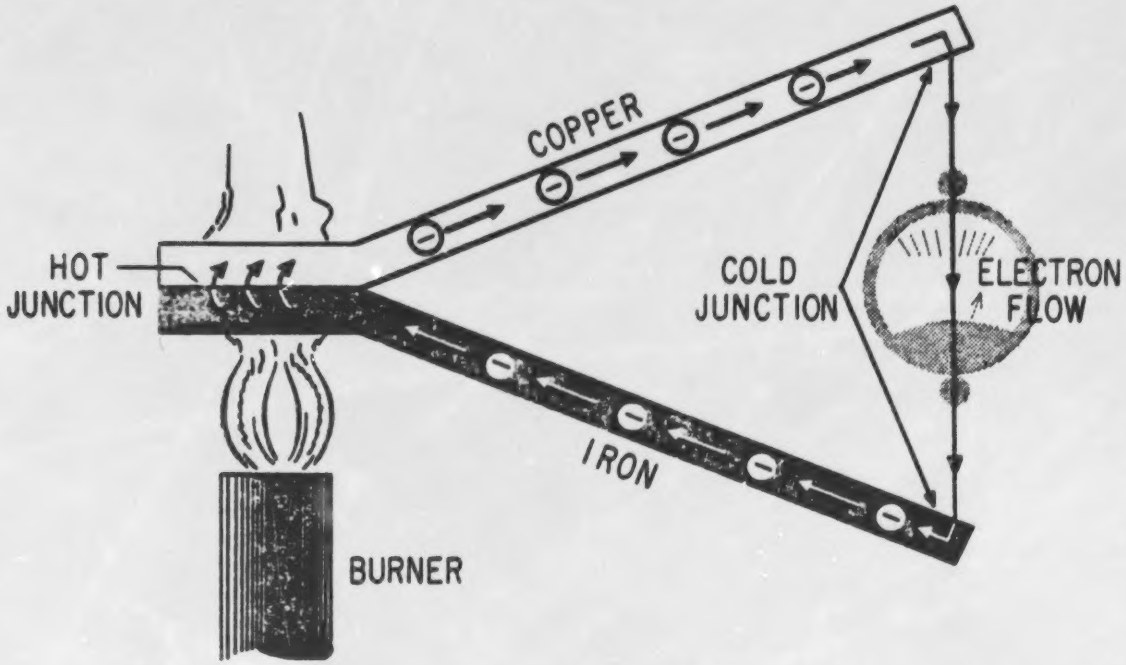
HOT JUNCTION
COPPER
COLD JUNCTION
ELECTRON FLOW
IRON
BURNER

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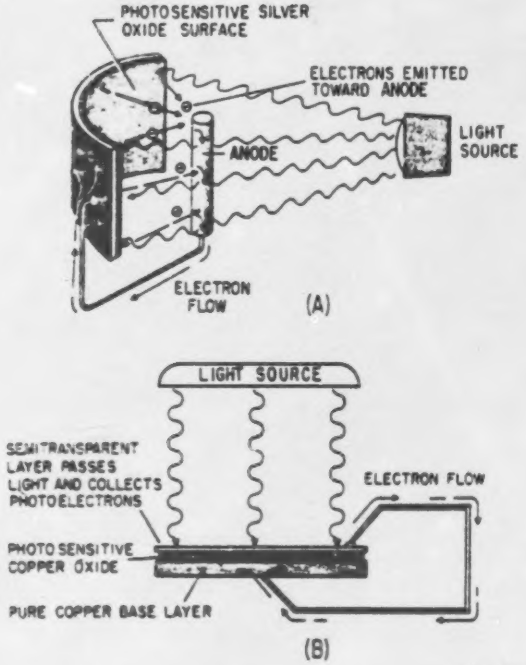
Figure 2-21.—Voltage produced by heat.


PHOTOSENSITIVE SILVER OXIDE SURFACE
ELECTRONS EMITTED TOWARD ANODE
LIGHT SOURCE
ANODE
ELECTRON FLOW
(A)
LIGHT SOURCE
SEMITRANSPARENT LAYER PASSES LIGHT AND COLLECTS PHOTOELECTRONS
ELECTRON FLOW
PHOTOSENSITIVE COPPER OXIDE
PURE COPPER BASE LAYER
(B)

BE.23

Figure 2-22.—Voltage produced by light.

A photocell's power capacity is very small. However, it reacts to light-intensity variations in an extremely short time. This characteristic makes the photocell very useful in detecting or accurately controlling a great number of processes or operations. For instance, the photoelectric cell, or some form of the photoelectric principle, is used in television cameras, automatic manufacturing process controls, door openers, burglar alarms, and so forth.

VOLTAGE PRODUCED BY CHEMICAL ACTION

Up to this point, it has been shown that electrons may be removed from their parent atoms and set in motion by energy derived from a source of friction, pressure, heat, or light. In general, these forms of energy do not alter the molecules of the substances being acted upon. That is, molecules are not usually added, taken away, or split-up when subjected to these four forms of energy. Only electrons are involved.

When the molecules of a substance are altered, the action is referred to as CHEMICAL. For instance, if the molecules of a substance combines with atoms of another substance, or gives up atoms of its own, the action is chemical in nature. Such action always changes the chemical name and characteristics of the substance affected. For instance, when atoms of oxygen from the air come in contact with bare iron, they merge with the molecules of iron. This iron is "oxidized." It has changed chemically from iron to iron oxide, or "rust." Its molecules have been altered by chemical action.

In some cases, when atoms are added to or taken away from the molecules of a substance, the chemical change will cause the substance to take on an electric charge. The process of producing a voltage by chemical action is used in batteries and is explained in chapter 3.

VOLTAGE PRODUCED BY MAGNETISM

Magnets or magnetic devices are used for thousands of different jobs. One of the most useful and widely employed applications of magnets is in the production of vast quantities of electric power from mechanical sources. The mechanical power may be provided by a number of different sources, such as gasoline or diesel engines, and water or steam turbines. However, the final conversion of these source energies to electricity is done by generators employing the principle of electromagnetic induction. These generators, of many types and sizes, are discussed in later chapters of this manual. The important subject to be discussed here is the fundamental operating principle of ALL such electromagnetic-induction generators.

To begin with, there are three fundamental conditions which must exist before a voltage can be produced by magnetism. They are as follows:

1. There must be a CONDUCTOR, in which the voltage will be produced.
2. There must be a MAGNETIC FIELD in the conductor's vicinity.
3. There must be relative motion between the field and the conductor. The conductor must be moved so as to cut across the magnetic lines of force, or the field must be moved so that the lines of force are cut by the conductor.

In accordance with these conditions, when a conductor or conductors MOVE ACROSS a magnetic field so as to cut the lines of force, electrons WITHIN THE CONDUCTOR are impelled in one direction or another. Thus, an electric force, or voltage, is created.

In figure 2-23, note the presence of the three conditions needed for creating an induced voltage:

1. A magnetic field exists between the poles of the C-shaped magnet.
2. There is a conductor (copper wire).
3. There is relative motion. The wire is moved back and forth ACROSS the magnetic field.

In figure 2-23 (A), the conductor is moving TOWARD the front of the page. This occurs because of the magnetically induced emf acting on the electrons in the copper. The right-hand end becomes negative, and the left-hand end positive. The conductor is stopped (B), motion is eliminated (one of the three required conditions), and there is no longer an induced emf. Consequently, there is no longer any difference in potential between the two ends of the wire. The conductor at (C) is moving away from the front of the page. An induced emf is again created. However, note carefully that the REVERSAL OF MOTION has caused a REVERSAL OF DIRECTION in the induced emf.

If a path for electron flow is provided between the ends of the conductor, electrons will leave the negative end and flow to the positive end. This condition is shown in part (D). Electron flow will continue as long as the emf exists. In studying figure 2-23, it should be noted that the induced emf could also have been created by holding the conductor stationary and moving the magnetic field back and forth.

The more complex aspects of power generation by use of mechanical motion and magnetism are discussed in later chapters of this manual under the heading "Generators."

ELECTRIC CURRENT

The drift or flow of electrons through a conductor is called electric current or electron flow. During the early study of electricity, electric current was erroneously assumed to be a movement of electrons from a positive potential to a negative potential. This assumption, termed conventional current flow, is a concept that became entrenched in the minds of many scientists, technicians, and writers. Consequently, conventional current flow is indicated in many textbooks, and this concept of electron movement should be realized. However, since this early concept, it has been positively determined that the direction of electron movement is from a region of negative potential to a region of less negative potential or more positive potential. Various terms may be used in this manual and other textbooks to describe current flow. The terms current, current flow, electron flow,

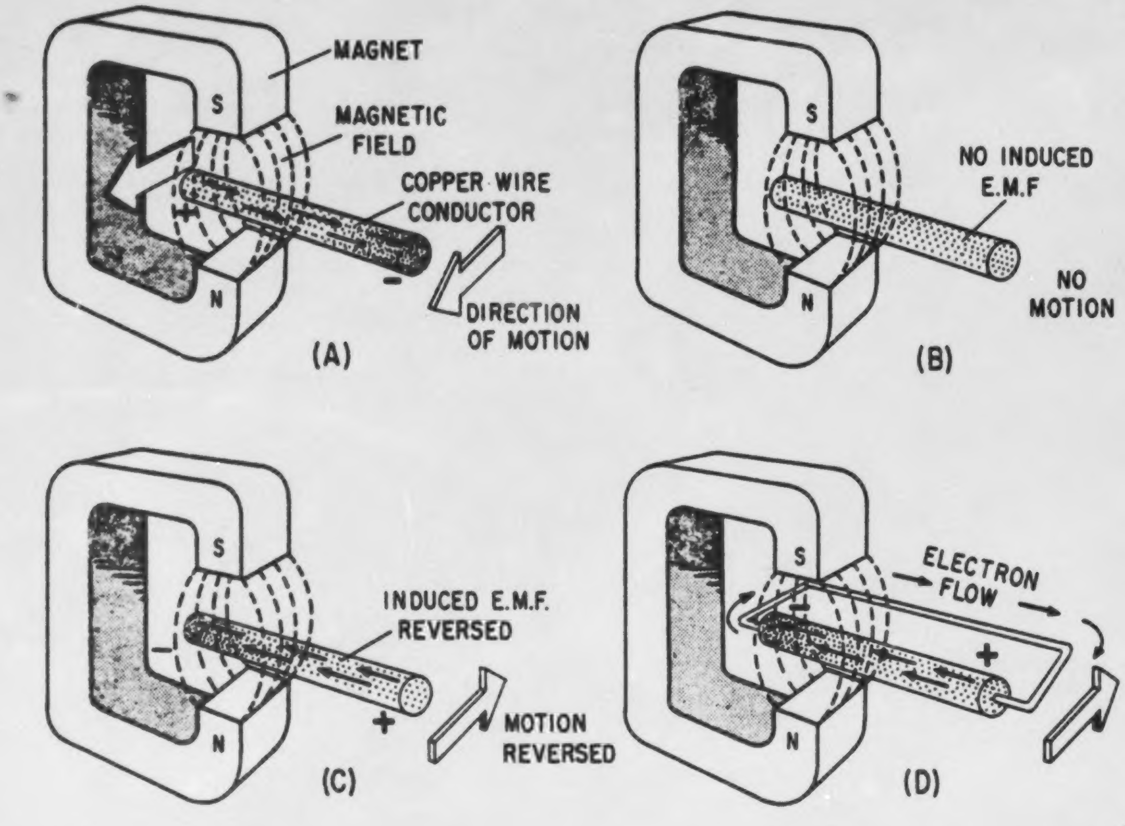


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Figure 2-23.—Voltage produced by magnetism.

electron current, etc., may be used to describe the same phenomenon; however, the reader should realize that regardless of the term used, the movement of electrons will be from a negative potential to a positive potential.

Electric current is generally classified into two general types—direct current and alternating current. Direct current flows in the same direction whereas an alternating current periodically reverses direction. These two types of current are discussed in greater detail later in this manual.

In order to determine the amount (number) of electrons flowing in a given conductor, it is necessary to adopt a unit of measurement of current flow. The term AMPERE is used to define the unit of measurement of the rate at which current flows (electron flow). The symbol for current flow is I. Current flow is measured in amperes. The abbreviation for ampere is amp. One ampere may be defined as the flow of 6.28×10^{18} electrons per second past a fixed point in a conductor.

A unit quantity of electricity is moved through an electric circuit when 1 ampere of current flows for 1 second of time. This unit is equivalent to 6.28×10^{18} electrons, and is called the COULOMB. The coulomb is to electricity as the gallon is to water. The symbol for the coulomb is Q. The rate of flow of current in amperes and the quantity of electricity moved through a circuit are related by the common factor of time. Thus, the quantity of electric charge, in coulombs, moved through a circuit is equal to the product of the current in amperes, I, and the duration of flow in seconds, t. Expressed as an equation, $Q = It$.

For example, if a current of 2 amperes flows through a circuit for 10 seconds the quantity of electricity moved through the circuit is 2 x 10, or 20 coulombs. Conversely, current flow may be expressed in terms of coulombs and time in seconds. Thus, if 20 coulombs are moved through a circuit in 10 seconds, the average current flow is $\frac{20}{10}$, or 2 amperes. Note that the current flow in amperes implies the rate of flow of coulombs per second without indicating either coulombs or seconds. Thus a current flow of 2 amperes is equivalent to a rate of flow of 2 coulombs per second. Frequently, the ampere is much too large a unit for practical utilization. Therefore, the milliampere (ma), one-thousandth of an ampere (or the microampere, one-millionth of an ampere), is used. The device used to measure current is called an ammeter and is discussed later in this manual.

RESISTANCE

Every material offers some resistance, or opposition, to the flow of electric current through it. Good conductors, such as copper, silver, and aluminum, offer very little resistance. Poor conductors, or insulators, such as glass, wood, and paper, offer a high resistance to current flow.

The size and type of material of the wires in an electric circuit are chosen so as to keep the electrical resistance as low as possible. In this way, current can flow easily through the conductors, just as water flows through the pipe between the tanks in figure 2-19. If the water pressure remains constant the flow of water in the pipe will depend on how far the valve is opened. The smaller the opening, the greater the opposition to the flow, and the smaller will be the rate of flow in gallons per second.

In the electric circuit, the larger the diameter of the wires, the lower will be their electrical resistance (opposition) to the flow of current through them. In the water analogy, pipe friction opposes the flow of water between the tanks. This friction is similar to electrical resistance. The resistance of the pipe to the flow of water through it depends upon (1) the length of the pipe, (2) the diameter of the pipe, and (3) the nature of the inside walls (rough or smooth). Similarly, the electrical resistance of the conductors depends upon (1) the length of the wires, (2) the diameter of the wires, and (3) the material of the wires (copper, aluminum, etc.).

Temperature also affects the resistance of electrical conductors to some extent. In most conductors (copper, aluminum, iron, etc.) the resistance increases with temperature. Carbon is an exception. In carbon the resistance decreases as temperature increases. Certain alloys of metals (manganin and constantan) have resistance that does not change appreciably with temperature.

The relative resistance of several conductors of the same length and cross section is given in the following list with silver as a standard of 1 and the remaining metals arranged in an order of ascending resistance:

Silver	1.0
Copper	1.08
Gold	1.4
Aluminum	1.8
Platinum	7.0
Lead	13.5

The resistance in an electrical circuit is expressed by the symbol R. Manufactured circuit parts containing definite amounts of resistance are called RESISTORS. Resistance (R) is measured in OHMS. One ohm is the resistance of a circuit element, or circuit, that permits a steady current of 1 ampere (1 coulomb per second) to flow when a steady emf of 1 volt is applied to the circuit.

CONDUCTANCE

Electricity is a study that is frequently explained in terms of opposites. The term that is exactly the opposite of resistance is conductance. Conductance (G) is the ability of a material to pass electrons. The unit of conductance is the Mho, which is ohm spelled backwards. Whereas the symbol used to represent resistance is the Greek letter omega (Ω), the symbol used to represent conductance is the Greek letter omega upside down (℧). The relationship that exists between resistance and conductance is the reciprocal. A reciprocal of a number is obtained by dividing the number into one. In terms of resistance and conductance:

$$R = \frac{1}{G}$$

$$G = \frac{1}{R}$$

If the resistance of a material is known, dividing its value into one will give its conductance. Similarly, if the conductance is known, dividing its value into one will give its resistance.

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CHAPTER 4

SERIES D-C CIRCUITS

SIMPLE ELECTRIC CIRCUIT

Whenever two unequal charges are connected by a conductor, a complete pathway for current flow exist. Current will flow from the negative to the positive charge. This was illustrated in chapter 2.

An electric circuit is a completed conducting pathway, consisting not only of the conductor, but including the path through the voltage source. Current flows from the positive terminal through the source, emerging at the negative terminal. As an example, a lamp connected by conductors across a dry cell forms a simple electric circuit. (Refer to fig. 4-1.)

Current flows from the negative (-) terminal of the battery through the lamp to the positive (+) battery terminal, and continues by going through the battery from the positive (+) terminal to the negative (-) terminal. As long as this pathway is unbroken, it is a closed circuit and current will flow. However, if the path is broken at ANY point, it is an open circuit and no current flows. (See fig. 4-1 (B).)

Current flow in the external circuit is the movement of electrons in the direction indicated by the arrows (from the negative terminal through the lamp to the positive terminal). (See fig. 4-1 (A).) Current flow in the internal battery circuit is the simultaneous movement in opposite directions of positive hydrogen ions toward the positive terminal of the battery and negative ions toward the negative terminal.

SCHEMATIC REPRESENTATION

A SCHEMATIC is a diagram in which symbols are used for the various components instead of pictures. These symbols are used in an effort to make the diagrams easier to draw and easier to understand. In this respect, schematic symbols aid the technician in the same way that shorthand aids the stenographer. In previous chapters the schematic symbols for cells and resistances were presented. These symbols will now be used to discuss the circuits of figure 4-1.

A schematic diagram of a basic circuit is shown in figure 4-2. The battery is designated by the letter symbols E_{bb}, the light bulb in the circuit is labeled R_1. Since in reality the light bulb element is nothing more than a wire wound resistor, the conventional resistor symbol is used for the bulb in this discussion. It should be noted, however, that the light bulb has its own specific schematic symbol and is not normally drawn as a resistor. The standard symbol used for a light bulb is discussed at a later time when need arises.

In studies of electricity and electronics many circuits are analyzed which consist mainly of specially designed resistive components. As previously stated, these components are called resistors. Throughout the remaining analysis of the basic circuit, the resistive component will be a physical resistor. However, the resistive component could be any one of several electrical devices.

A closed loop of wire (conductor) is not necessarily a circuit. A source of voltage must be included to make it an electric circuit. In any electric circuit where electrons move around a closed loop, current, voltage, and resistance are present. The physical pathway for current flow is actually the circuit. Its resistance controls the amount of current flow around the circuit. By knowing any two of the three quantities, such as voltage and current, the third (resistance) may be determined. This is done mathematically by the use of Ohm's LAW.

OHM'S LAW

In the early part of the 19th century Georg Simon Ohm proved by experiment that a precise

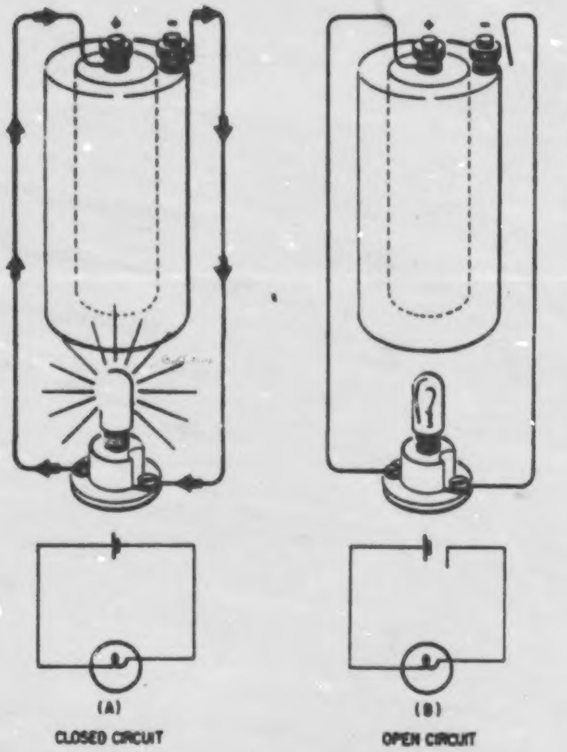

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Figure 4-1.—(A) Simple electric circuit (closed); (B) simple electric circuit (open).

relationship exists between current, voltage, and resistance. This relationship is called Ohm's Law and is stated as follows:

The current in a circuit is DIRECTLY proportional to the applied voltage and INVERSELY proportional to the circuit resistance. Ohm's Law may be expressed as an equation:

$$I = \frac{E}{R} \qquad (4\text{-}1)$$

Where: I = current in amperes

E = voltage in volts

R = resistance in ohms

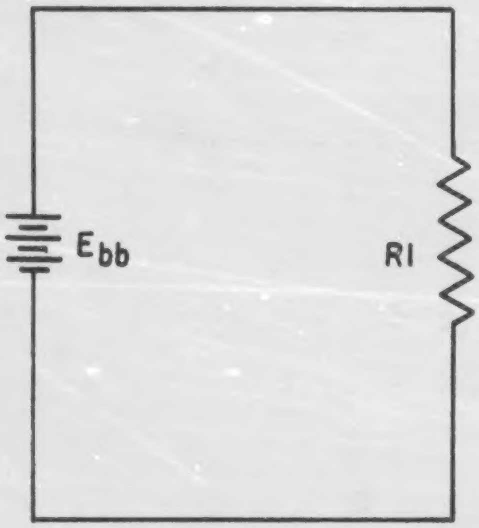

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Figure 4-2.—Schematic diagram of a basic circuit.

If any two of the quantities in equation (4-1) are known, the third may be easily found. For example, Figure 4-3 shows a circuit containing a resistance of 1.5 ohms and a source voltage of 1.5 volts. How much current flows in the circuit?

Given: E = 1.5 volts

R = 1.5 ohms

I = ?

Solution: $I = \frac{E}{R}$

$I = \frac{1.5}{1.5}$

I = 1 ampere

To observe the effect of source voltage on circuit current, the above problem will be solved again using double the previous source voltage.

Given: E = 3 volts

R = 1.5 ohms

I = ?

Solution: $I = \frac{E}{R}$

$I = \frac{3}{1.5}$

I = 2 amperes

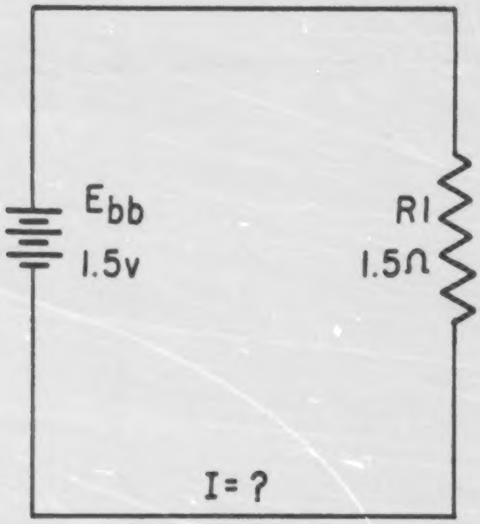

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Figure 4-3.—Determining current in a basic circuit.

Notice that as the source voltage doubles, the circuit current also doubles.

Circuit current is directly proportional to applied voltage and will change by the same factor that the voltage changes.

To verify the statement that current is inversely proportional to resistance, assume the resistor in figure 4-3 to have a value of 3 ohms.

Given: $E = 1.5$ volts

$R = 3$ ohms

$I = ?$

Solution: $I = \frac{E}{R}$

$I = \frac{1.5}{3}$

$I = 0.5$ ampere

Comparing this current of 0.5 ampere for the 3 ohm resistor, to the 1 ampere of current obtained with the 1.5-ohm resistor, shows that doubling the resistance will reduce the current to one half the original value. Circuit current is inversely proportional to the circuit resistance.

In many circuit applications current is known and either the voltage or the resistance will be the unknown quantity. To solve a problem in which current and resistance are known, the basic formula for Ohm's Law must be transposed to solve for E as follows:

Basic equation: $I = \frac{E}{R}$ (4-1)

Multiply both sides of the equation by R.

$$IR = \frac{E}{\cancel{R}}\cancel{R}$$

$$IR = E$$

$$E = IR \qquad (4\text{-}2)$$

To transpose the basic formula when resistance is unknown:

Basic equation: $I = \frac{E}{R}$ (4-1)

Multiply both sides of the equation by R.

$$IR = \frac{E}{\cancel{R}}\cancel{R}$$

$$IR = E$$

Divide both sides of the equation by I.

$$\frac{\cancel{I}R}{\cancel{I}} \quad \frac{E}{I}$$

$$R = \frac{E}{I} \qquad (4\text{-}3)$$

Example: What voltage is required to properly light a lamp having a resistance of 10 ohms and a current rating of 1 ampere?

First draw a circuit like figure 4-4 including all the given information.

Given: $R = 10$ ohms

$I = 1$ ampere

$E = ?$

Solution: $E = IR$

$E = 1 \times 10$

$E = 10$ volts

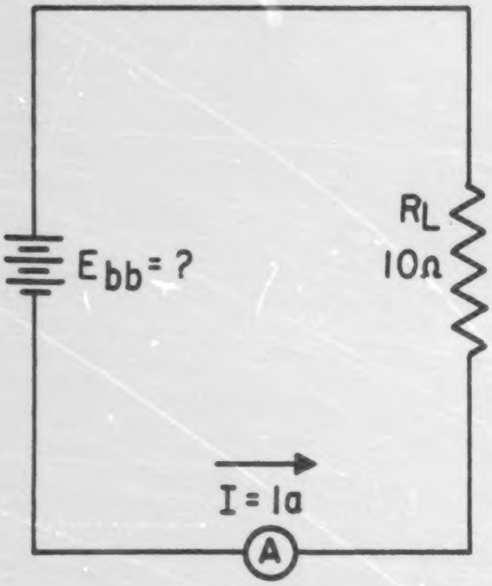

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Figure 4-4.—Determining voltage in a basic circuit.

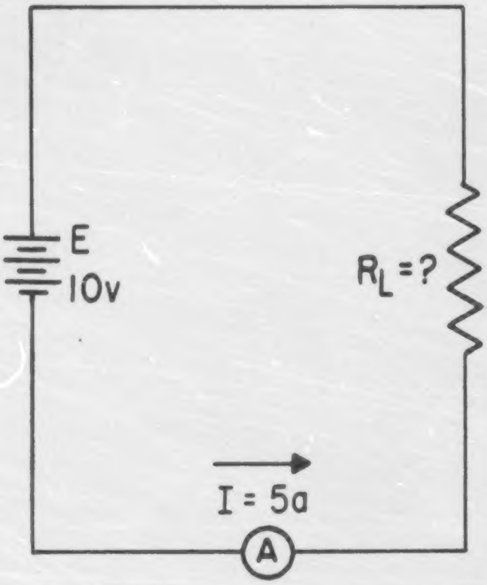

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Figure 4-5.—Determining resistance in a basic circuit.

Example: When a 10 volt source is connected to a circuit, the circuit draws 5 amperes of current from the source. How much resistance is contained in the circuit?

Given: $E = 10$ volts

$I = 5$

$R = ?$

Draw and label a circuit like figure 4-5.

Solution: $$R = \frac{E}{I} \qquad (4\text{-}3)$$

$$R = \frac{10}{5}$$

$R = 2$ ohms

Although the three equations representing Ohm's Law are fairly simple, they are perhaps the most important of all electrical equations. These three equations and the law they represent must be thoroughly understood before continuing on to more advanced theory.

GRAPHICAL ANALYSIS

One of the most valuable methods of inquiry available to the technician is that of graphical analysis. No other method provides a more convenient or more rapid way to observe the characteristics of an electrical device.

The first step in constructing a graph consists of obtaining a table of data from which the graph will evolve. The information in the table can be obtained experimentally by taking laboratory measurements on the device under examination, or can be obtained theoretically through a series of computations. The latter method will be used here.

Let us assume that the characteristics of the circuit shown in figure 4-6 are to be investigated using Ohm's Law and graphical methods. Since there are three variables (E, I, and R) under consideration, there are three unique graphs that may be constructed.

In constructing any graph of electrical quantities, it is standard practice to vary one quantity in a specified way, and note the changes which occur in a second quantity. The quantity which is intentionally varied is called the independent variable and is plotted on the X-AXIS. The second quantity which changes as a result of changes in the first quantity is called the dependent variable and is plotted on the Y-AXIS. Any other quantities involved are held constant.

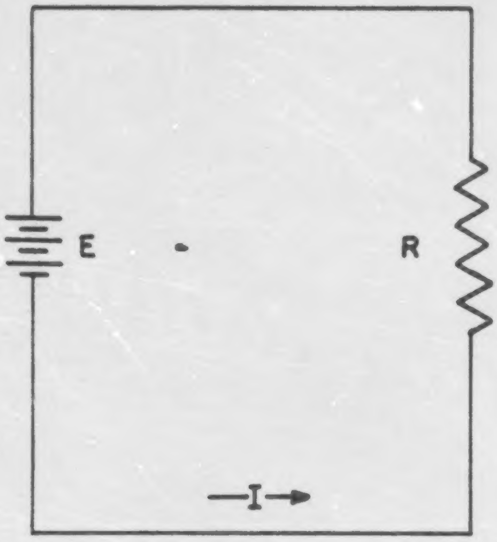

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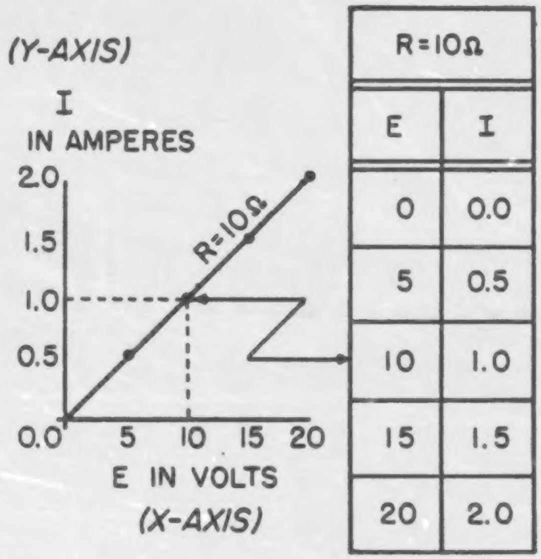
Figure 4-6.—Three variables in a series circuit.

In the circuit of figure 4-6 the resistance will remain fixed (constant) and the voltage (independent variable) will be varied. The resulting changes in current (dependent variable) will then be graphed.

To aid in compiling the data, a table of values is completed as shown in figure 4-7. This table shows R to be held constant at 10 ohms as E is varied from 0 to 20 volts in 5-volt steps. Through the use of Ohm's Law the value of current in column two of the table can be calculated for each value of voltage in column one. When the table is complete, the information it contains can be used to construct the graph in figure 4-7. For example, when the voltage applied to the 10-ohm resistor is 10 volts, the current is 1 ampere. These values of current and voltage determine a point on the graph. When all the points have been plotted, a smooth curve is drawn through the points. This curve is called the volt-ampere characteristic for the 10-ohm resistor.

Through the use of this curve the value of current through the resistor can be quickly determined for any value of voltage between 0 and 20 volts.

A very important characteristic of a fixed resistor is illustrated by the graph in figure 4-7. Since the volt-ampere characteristic curve is a straight line, it shows that equal changes of voltage across a resistor produce equal changes in current through the resistor. Because of this straight line characteristic, the fixed resistor is called a linear device.



R=10Ω	
E	I
0	0.0
5	0.5
10	1.0
15	1.5
20	2.0

BE.47
Figure 4-7.—Volt-ampere characteristic.

This graph illustrates an important characteristic of the basic law—namely, the current varies directly with the applied voltage if the resistance is constant.

If the voltage across a load is maintained at a constant value, the current through the load will depend solely upon the effective resistance of the load. For example, with a constant voltage of 12 volts and a resistance of 12 ohms, the current will be $\frac{12}{12}$, or 1 ampere. If the resistance is halved, the current will be doubled; if the resistance is doubled, the current will be halved. In other words, the current will vary inversely with the resistance.

If the resistance of the load is reduced in steps of 2 ohms starting at 12 ohms and continuing to 2 ohms, the current through the load becomes $\frac{12}{10} = 1.2$ amperes; $\frac{12}{8} = 1.5$ amperes; $\frac{12}{6} = 2$ amperes; and so forth. The relation between current and resistance in this example is expressed as a graph (fig. 4-8), whose equation is $I = \frac{12}{R}$. The numerator of the fraction represents a constant value of 12 volts in this example. As R approaches a small value the current approaches a very large value. The example illustrates a second equally important relation in Ohm's law—namely, that the current varies inversely with the resistance.

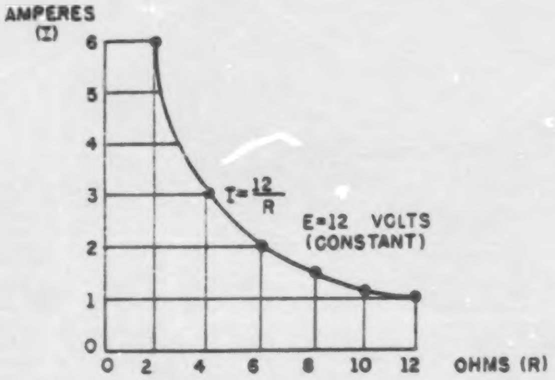


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Figure 4-8.—Relation between current and resistance.

If the current through the load is maintained constant at 5 amperes, the voltage across the load will depend upon the resistance of the load and will vary directly with it. The relation between voltage and resistance is shown in the graph of figure 4-9. Values of resistance are plotted horizontally along the X-axis to the right of the origin, and corresponding values of voltage are plotted vertically along the Y-axis above the origin. The graph is a straight line having the equation E = 5R. The coefficient 5 represents the assumed current of 5 amperes which is constant in this example. Thus, a third important relation is illustrated—namely, that the voltage across a device varies directly with the effective resistance of the device provided the current through the device is maintained constant.

APPLYING OHM'S LAW

Equation (4-1) may be transposed to solve for the resistance if the current and voltage are known, or to solve for the voltage if the current and resistance are known. Thus, $R = \frac{E}{I}$ and $E = IR$. For example, if the voltage across a device is 50 volts and the current through it is 2 amperes, the resistance of the device will be $\frac{50}{2}$, or 25 ohms. Also, if the current through a wire is 3 amperes and the resistance of the wire is 0.5 ohm, the voltage drop across the wire will be 3 x 0.5, or 1.5 volts.

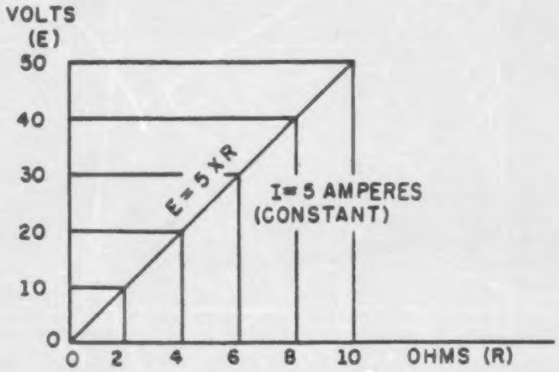

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Figure 4-9.—Graph of voltage vs. resistance with constant current.

Equation (4-1) and its transpositions may be obtained readily with the aid of figure 4-10. The circle containing E, I, and R is divided into two parts with E above the line and IR below it. To determine the unknown quantity, first cover that quantity with a finger. The location of the remaining uncovered letters in the circle will indicate the mathematical operation to be performed. For example, to find I, cover I with a finger. The uncovered letters indicate that E is to be divided by R, or $I = \frac{E}{R}$. To find E, cover E. The result indicates that I is to be multiplied by R, or $E = IR$. To find R, cover R. The result indicates that E is to be divided by I, or $R = \frac{E}{I}$.

The beginning student is cautioned not to rely wholly on the use of this diagram when transposing simple formulas but rather to use it to supplement his knowledge of the algebraic method. Algebra is a basic tool in the solution of electrical problems and the importance of knowing how to use it should not be underemphasized or bypassed after the student has learned a shortcut method such as the one indicated in this figure.

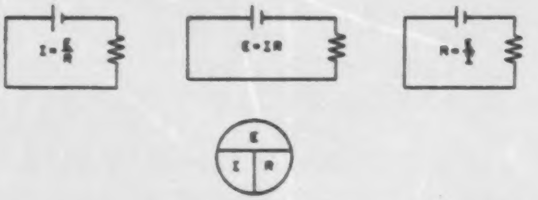

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Figure 4-10.—Ohm's law in diagram form.

ELECTRIC POWER AND ENERGY

POWER

Power, whether electrical or mechanical, pertains to the rate at which work is being done. Work is done whenever a force causes motion. If a mechanical force is used to lift or move a weight, work is done. However, force exerted WITHOUT causing motion, such as the force of a compressed spring acting between two fixed objects, does not constitute work.

Previously, it was shown that voltage is electrical force, and that voltage forces current to flow in a closed circuit. However, when voltage exists between two points, but current cannot flow, no work is done. This is similar to the spring under tension that produced no motion. When voltage causes electrons to move, work is done. The instantaneous RATE at which this work is done is called the electric power rate, and its measure is the watt.

A total amount of work may be done in different lengths of time. For example, a given number of electrons may be moved from one point to another in 1 second or in 1 hour, depending on the RATE at which they are moved. In both cases, total work done is the same. However, when the work is done in a short time, the wattage, or INSTANTANEOUS POWER RATE is greater than when the same amount of work is done over a longer period of time.

As stated, the basic unit of power is the WATT, and it is equal to the voltage across a circuit multiplied by current through the circuit. This represents the rate at any given instant at which work is being done in moving electrons through the circuit. The symbol P indicates electrical power. Thus, the basic power formula is P = E x I. E is the voltage across and I is the current through the resistor or circuit whose power is being measured. The amount of power will change when either voltage or current, or both voltage and current change. This relation is shown with the graph and simple circuit in figure 4-11.

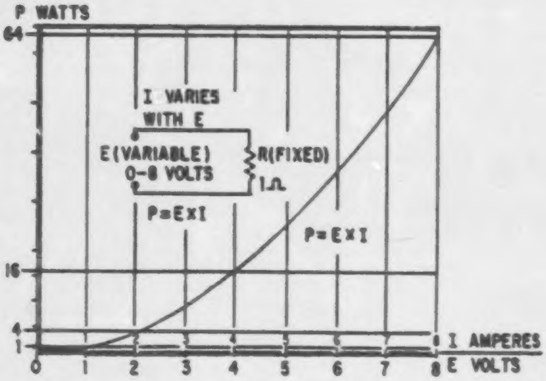

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Figure 4-11.—Graph of power related to changing voltage and current.

The resistance is 1 ohm, and does not change. Voltage E is increased in steps of 1 volt from 0 to 8. By applying Ohm's law, the current I is determined for each step of voltage. For instance, when E is 1 volt, the current I is

$$I = \frac{E}{R} \qquad (4\text{-}1)$$

$$I = \frac{1}{1}$$

$$I = 1 \text{ ampere}$$

Power P, in watts, is determined by applying the basic power formula P = E x I. When E is 1 volt, I is 1 ampere, so P is

$$P = E \times I$$

$$P = 1 \times 1$$

$$P = 1 \text{ watt}$$

However, when E is 2 volts, and I is 2 amperes, P becomes:

$$P = E \times I$$

$$P = 2 \times 2$$

$$P = 4 \text{ watts}$$

It is important to note that when voltage E was doubled from 1 volt to 2 volts, power P doubled TWICE from 1 watt to 4 watts. This occurred because the doubling of voltage caused a doubling of current, therefore power was doubled twice. This is shown as follows:

$$P = E \times I$$

$$P = E \times 2 \times I \times 2$$

$$P = (1 \times 2) \times (1 \times 2)$$

$$P = 2 \times 2$$

$$P = 4 \text{ watts.}$$

This shows that the power in a circuit of fixed resistance is caused to change at a SQUARE rate by changes in applied voltage. Thus, the basic power formula $P = E \times I$ may also be $P = \frac{E^2}{R}$. To further illustrate the square-rate relation between power and voltage, note on the graph that power is the square of voltage (when resistance is 1 ohm). For instance, when E is 2 volts, P is 4 watts. When E is doubled to 4 volts, P is 16 watts, and when E is redoubled to 8 volts, P becomes 64 watts. When resistance is any value other than 1 ohm, power will not be the exact square of voltage in quantity but it will still vary at a square rate. That is, regardless of the value of resistance, so long as it is fixed, when voltage doubles, power doubles twice. Also, when the voltage is halved, power is halved twice.

Another important relation may be seen by studying figure 4-11. Thus far power has been calculated with voltage and current ($P = E \times I$), and with voltage and resistance ($P = \frac{E^2}{R}$). Referring to figure 4-11, note that power also varies as the square of current just as it does with voltage. Thus, another formula for power, with current and resistance as its factors, is $P = I^2R$. Note that resistance R is a divisor in one formula ($P = \frac{E^2}{R}$), but is a multiplier in the other ($P = I^2R$). This is true because of substitutions in the original formula $P = E \times I$. That is, the Ohm's law equivalent of I is $\frac{E}{R}$. If this equivalent is substituted for I in the power formula $P = E \times I$, the results are as follows:

$$P = E \times I \qquad (4\text{-}4)$$

$$P = E \times \frac{E}{R}$$

$$P = \frac{E^2}{R} \qquad (4\text{-}5)$$

In addition, the Ohm's law equivalent of E is I x R. If this equivalent is substituted for E, the power formula becomes

$$P = E \times I$$

$$P = (I \times R) \times I$$

$$P = I^2R \qquad (4\text{-}6)$$

In the foregoing discussion, and in figure 4-11, it was shown how variations of the voltage impressed across a fixed resistance caused variations in the circuit current and power. The following discussion refers to figure 4-12. In this circuit, the voltage E is fixed at 10 volts, and the resistance R is the variable factor. (The arrow through the resistance means it is variable).

When the resistance R is set at 1 ohm, the current I is 10 amperes, and the power is

$$P = I^2R \qquad (4\text{-}6)$$

$$P = (10^2) \times R$$

$$P = 100 \times 1$$

$$P = 100 \text{ watts}$$

When the resistance is doubled to 2 ohms, this same calculation will show that power is halved to 50 watts, as the graph shows. Subsequent redoubling of the resistance to 4 and then to 8 ohms causes the power to be halved each time to 25 and 12-1/2 watts, respectively. Conversely, you should note the relation when starting with resistance at 10 ohms, with 10 watts of power. If resistance is halved to 5 ohms, power is doubled to 20 watts.

In figures 4-11 and 4-12, current and power were caused to vary as a function of voltage, in one case, and of resistance in the other. In figure 4-13, however, current is held constant.

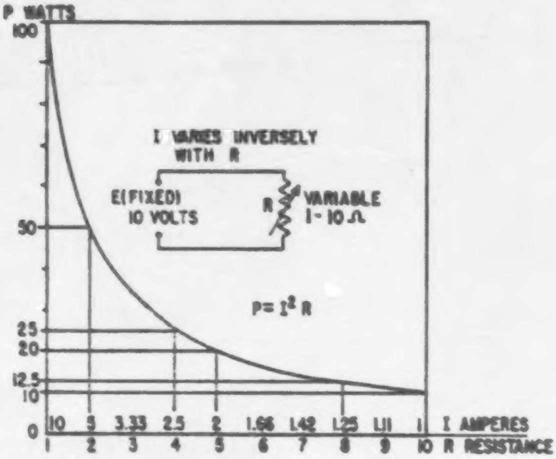

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Figure 4-12.—Graph of power related to changing resistance and current.

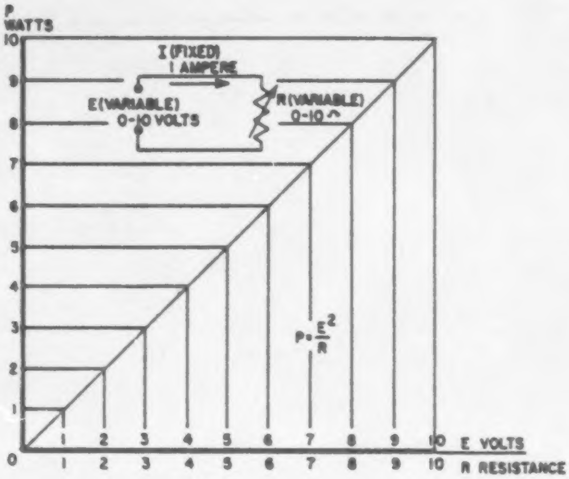

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Figure 4-13.—Graph of power related to changing voltage and resistance.

This is done by raising or lowering voltage and resistance equally and directly with each other. The resulting variations in power are linear with those changes. That is, power is changed step-for-step with voltage. The changing resistance maintains a constant current despite changes of voltage. At any point on the graph, voltage divided by resistance is 1 ampere. Had the current been allowed to vary, power would have changed at a curved, or square rate, instead of linearly as on the graph.

Up to this point, four of the most important basic electrical quantities have been discussed. These are E, I, R, and P. It is of fundamental importance that you thoroughly understand the interrelation of these quantities. You should understand how any one of these quantities either controls or is controlled by the others in an electrical circuit. These relations are further explained in the treatment that follows. You should compare each statement carefully with its associated formula. Check each formula for correctness by applying it to the graphs in figures 4-11, 4-12, or 4-13. (The appropriate figure number is indicated after each of the following statements)

1. Power, as related to E and I: $P = EI$ (fig. 4-11).

   This formula states that P is the product of E multiplied by I, regardless of their individual values. If either E or I varies, P varies proportionally. If both E and I vary, P varies at a square rate.

2. Power, as related to I and R: $P = I^2R$ (fig. 4-12).

   This formula states that if R is held constant, and I is varied, P varies as the square of I, because I appears as a squared quantity (I^2) in the formula. Also, if I is held constant and R is varied, P varies directly and proportionally to R, because R is a multiplier in the formula.

3. Power, as related to E and R: $P = \frac{E^2}{R}$ (fig. 4-13).

   This formula states that if R is held constant as E is varied, P varies as the square of E, because E appears as a squared quantity (E^2) in the formula. Also, if E is held constant and R is varied, P varies inversely but proportionally to R, because R is a divisor in the formula.

In the preceding paragraph, P was expressed in terms of alternate pairs of the other three basic quantities E, I, and R. In practice, you should be able to express any one of the three basic quantities, as well as P, in terms of any two of the others. Figure 4-14 is a summary of twelve basic formulas you should know. The four quantities E, I, R, and P are at the center of the figure.

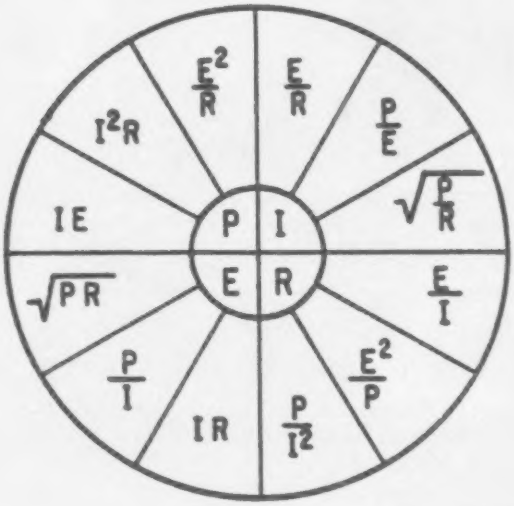

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Figure 4-14.—Summary of basic formulas.

Adjacent to each quantity are three segments. Note that in each segment, the basic quantity is expressed in terms of two other basic quantities, and no two segments are alike.

RATING OF ELECTRICAL DEVICES BY POWER

Electrical lamps, soldering irons, and motors are examples of electrical devices that are rated in watts. The wattage rating of a device indicates the rate at which the device converts electrical energy into another form of energy, such as light, heat, or motion.

For example, a 100-watt lamp will produce a brighter light than a 75-watt lamp, because it converts more electrical energy into light.

Electric soldering irons are of various wattage ratings, with the high-wattage irons changing more electrical energy to heat than those of low-wattage ratings.

If the normal wattage rating is exceeded, the equipment or device will overheat and probably be damaged. For example, if a lamp is rated 100 watts at 110 volts and is connected to a source of 220 volts, the current through the lamp will double. This will cause the lamp to use four times the wattage for which it is rated, and it will burn out quickly.

POWER CAPACITY OF ELECTRICAL DEVICES

Rather than indicate a device's ability to do work, its wattage rating may indicate the device's operating limits. These power limits generally are given as the maximum or minimum safe voltages and currents to which a device may be subjected. However, in cases where a device is not limited to any specific operating voltage, its limits are given directly in watts.

Resistors

A resistor is an example of such a device. It may be used in circuits with widely different voltages, depending on the desired current. However, the resistor has a maximum current limitation for each voltage applied to it. The product of the resistor's voltage and current at any time must not exceed a certain wattage.

Thus, resistors are rated in watts, in addition to their ohmic resistance. Resistors of the same resistance value are available in different wattage values. Carbon resistors, for example, are commonly made in wattage ratings of 1/3, 1/2, 1, and 2 watts. (See fig. 4-15.) The larger the physical size of a carbon resistor, the higher its wattage rating, since a larger amount of material will absorb and give up heat more easily.

When resistors of wattage ratings greater than 2 watts are needed, wire-wound resistors

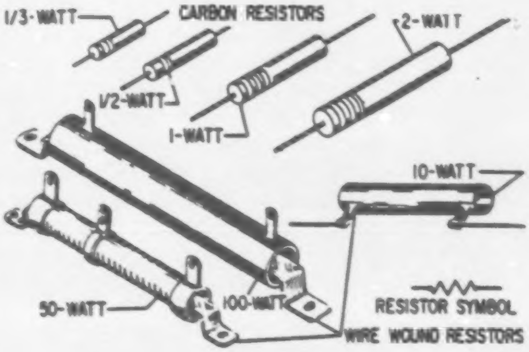

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Figure 4-15.—Resistors of different wattage ratings.

CHAPTER 5

PARALLEL D-C CIRCUITS

An adequate understanding of modern electrical equipment requires a progressive development in the study of typical electrical circuits. In stepping-stone fashion, the discussion of series d-c circuits will now be followed by a consideration of the characteristics of parallel d-c circuits. It will be shown how the principles applied to series circuits can be used to determine the reactions of such quantities as voltage, current, and resistance in parallel and series-parallel circuits.

Along with the progressive introduction of electrical theories and circuit characteristics comes a corresponding progression in the use of mathematical equations and problem solving methods. A basic knowledge of powers of ten, fractions, fractional equations, and the use of simultaneous equations is required for the comprehension of material presented in this chapter.

PARALLEL CIRCUIT CHARACTERISTICS

A parallel circuit is defined as one having more than one current path connected to a common voltage source. Parallel circuits, therefore, must contain two or more load resistances which are not connected in series. An example of a basic parallel circuit is shown in figure 5-1.

Commencing at the voltage source (E_{bb}) and tracing counterclockwise around the circuit, two complete and separate paths can be identified in which current can flow. One path is traced from the source through resistance R_1 and back to the source; the other, from the source through resistance R_2 and back to the source.

VOLTAGE

You have seen that the source voltage in a series circuit divides proportionately across each resistor in the circuit. In a parallel circuit (fig. 5-1), the same voltage is present across all the resistors of a parallel group. This voltage is equal to the applied voltage (R_{bb}). The foregoing statement can be expressed in equation form as

$$E_{bb} = E_{R1} = E_{R2} = E_{Rn} \qquad (5\text{-}1)$$

Voltage measurements taken across the resistors of a parallel circuit, as illustrated by figure 5-2, verify the above equation. Each voltmeter indicates the same amount of voltage. Notice that the voltage across each resistor is the same as the applied voltage.

Example. Assume that the current through a resistor of a parallel circuit is known to be 4.5 milliamperes (ma) and the value of the resistor is 30,000 ohms. Determine the potential across the resistor. The circuit is shown in figure 5-3.

Given:

$$R_2 = 30K$$

$$I_{R2} = 4.5 \text{ milliamperes}$$

Find:

$$E_{R2} = ?$$

$$E_{bb} = ?$$

Solution: Select proper equation.

$$E = IR \qquad (4\text{-}2)$$

Substitute known values:

$$E_{R2} = I_{R2} \times R_2$$

$$E_{R2} = 4.5 \text{ milliamperes} \times 30{,}000 \text{ ohms}$$

equal to the working force multiplied by the distance through which the force moved to do the work. This is the mechanical definition.

In electricity, total energy expended is equal to the rate at which work is done, multiplied by the length of time the rate is measured. Essentially, energy W is equal to power P times time t.

An equation for energy is derived by multiplying both sides of equation (4-4) by the common factor of time, t, and equating the expression to the energy, W, as

$$W = Pt$$

$$W = EIt. \qquad (4\text{-}7)$$

Similarly, both sides of equations (4-5) and (4-6) may be multiplied by the time factor, t, and equated to the energy, W, as

$$W = \frac{E^2}{R}\,t, \qquad (4\text{-}8)$$

and

$$W = I^2Rt. \qquad (4\text{-}9)$$

In the energy equations (4-7), (4-8), and (4-9), E is in volts and I in amperes. If t is expressed in hours, W will be in watt-hours.

If t is expressed in seconds, W will be in watt-seconds or joules (1 joule is equal to 1 watt-second). Since $Q = It$ (where Q is in coulombs, I in amperes, and t in seconds), it is possible to substitute Q for It in equation (4-7) with the resulting expression for energy. Thus

$$W = QE \qquad (4\text{-}10)$$

where W is the energy in joules or watt-seconds, Q is the quantity in coulombs, and E is in volts. (As explained in chapter 2, Q is the symbol for coulombs. This is the measure of a quantity of electrons. The Q is to electricity as the gallon is to water.)

Electrical energy is bought and sold in units of kilowatt-hours ($3{,}600 \times 10^3$ joules), and is totalized in large central generating stations in terms of megawatt-hours ($3{,}600 \times 10^6$ joules). For example, if the average demand over a 10-hour period is 70 megawatts, the total energy delivered is 70 x 10, or 700 megawatt-hours. This amount of energy is equivalent to 700 x 1,000 = 700,000 kilowatt-hours, or $700 \times 3{,}600 \times 10^6 = 2{,}520{,}000 \times 10^6$ joules. The most practical unit to use depends in part upon the magnitude of the quantity of energy involved, and in this example the megawatt-hour is appropriate.

SERIES CIRCUIT CHARACTERISTICS

As previously mentioned, an electric circuit is a complete path through which electrons can flow from the negative terminal of the voltage source, through the connecting wires or conductors, through the load or loads, and back to the positive terminal of the voltage source. A circuit is thus made up of a voltage source, the necessary connecting conductors, and the effective load.

If the circuit is arranged so that the electrons have only ONE possible path, the circuit is called a SERIES CIRCUIT. Therefore, a series circuit is defined as a circuit that contains only one path for current flow. Figure 4-18 shows a series circuit having several lamps.

RESISTANCE

Referring to figure 4-18, the current in a series circuit, in completing its electrical path, must flow through each lamp inserted into the circuit. Thus, each additional lamp offers added resistance. In a series circuit, THE TOTAL CIRCUIT RESISTANCE (R_T) IS EQUAL TO THE SUM OF THE INDIVIDUAL RESISTANCES.

As an equation:

$$R_T = R_1 + R_2 + R_3 \ldots R_n \qquad (4\text{-}11)$$

NOTE: The subscript n denotes any number of additional resistances that might be in the equation.

Example: Three resistors of 10 ohms, 15 ohms, and 30 ohms are connected in series across a battery whose emf is 110 volts (fig. 4-19). What is the total resistance?

Given:

R_1 = 10 ohms

R_2 = 15 ohms

R_3 = 30 ohms

R_T = ?

are used. Such resistors are made in ranges between 5 and 200 watts, with special types being used for power in excess of 200 watts.

Fuses

When current passes through a resistor, electric energy is transformed into heat, which raises the temperature of the resistor. If the temperature becomes too high, the resistor may be damaged. The metal wire in a wound resistor may melt, opening the circuit and interrupting current flow. This effect is used to an advantage in fuses.

Fuses are actually metal resistors with very low resistance values. They are designed to "blow out" and thus open a circuit when current exceeds the fuse's rated value.

When the power consumed by the fuse raises the temperature of its metal too high, the metal melts, or "blows." In service, fuses are generally connected as shown in figure 4-16.

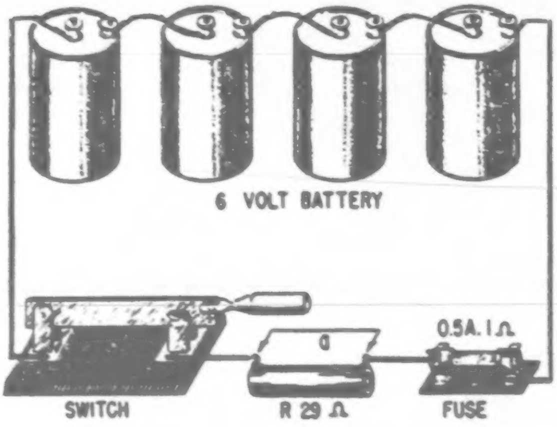

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Figure 4-16.—Simple fused circuit.

Note that all current flowing through the load resistance of 29 ohms must also flow through the half-ampere fuse. Under normal conditions, the total resistance would be 29 + 1 = 30 ohms. If the switch were closed, the current I would be

$$I = \frac{E}{R}$$

$$I = \frac{6}{30}$$

$$I = 0.2 \text{ ampere}$$

This would be less than the rated current of the fuse, and it would not open. However, if the short conductor (a, fig. 4-16) were connected, the load resistance would be bypassed, or "shorted out." Only the fuse resistance of one ohm would remain in the circuit. Current would then be

$$I = \frac{E}{R}$$

$$I = \frac{6}{1}$$

$$I = 6 \text{ amperes}$$

Six amperes of current will cause the half-ampere fuse to open very quickly, because its wattage rating is greatly exceeded.

There are a great number of different types and sizes of fuses presently in use. Figure 4-17 shows three of the most common types. Fuses are discussed in greater detail in chapter 14 of this manual.

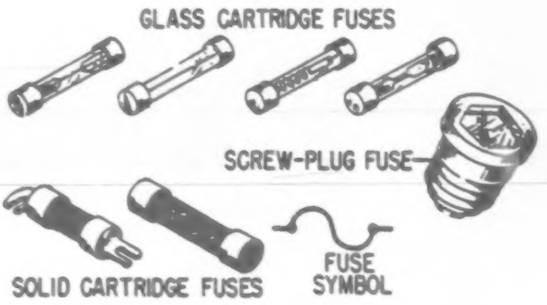

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Figure 4-17.—Typical fuse types.

ENERGY

Energy is defined as the ability to do work. Energy is expended when work is done, because it takes energy to maintain a force when that force acts through a distance. The total energy expended to do a certain amount of work is

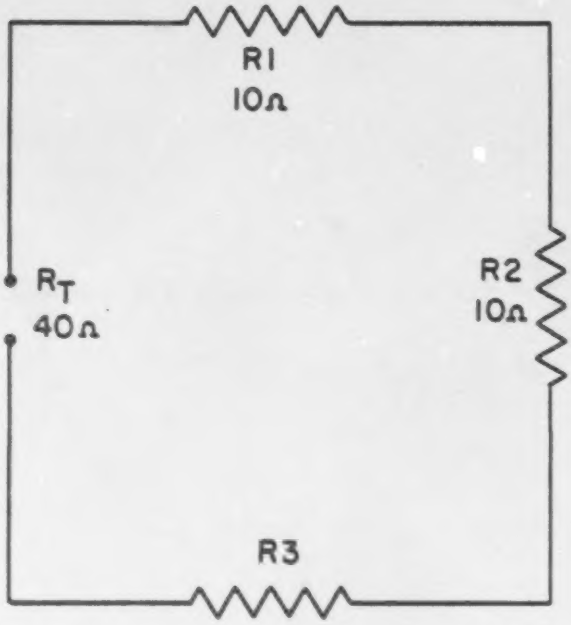

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Figure 4-20.—Calculating the value of one resistance in a series circuit.

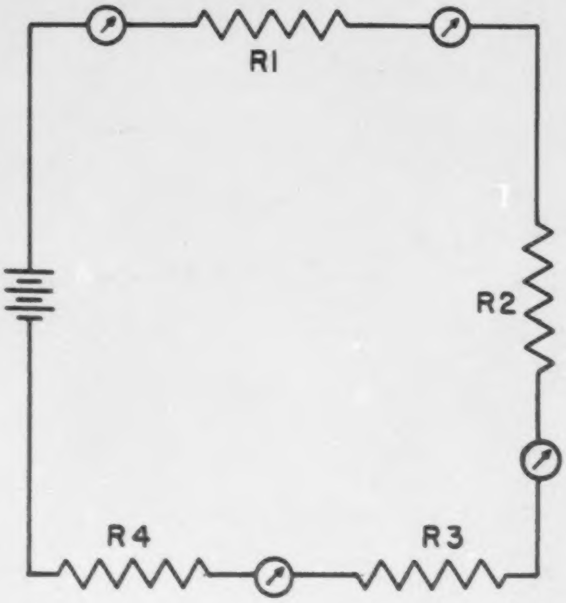

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Figure 4-21.—Current in a series circuit.

through each part of the circuit. To determine the current throughout a series circuit, only the current through one of the parts need be known.

The fact that the same current flows through each part of a series circuit can be verified by inserting ammeters into the circuit at various points as shown in figure 4-21. If this were done, each meter would be found to indicate the same value of current.

VOLTAGE

As stated previously, the voltage drop across the resistor in the basic circuit is the total voltage across the circuit and is equal to the applied voltage. The total voltage across a series circuit is also equal to the applied voltage, but consists of the sum of two or more individual voltage drops. In any series circuit the SUM of the resistor voltage drops must equal the source voltage. This statement can be proven by an examination of the circuit shown in figure 4-22. In this circuit a source potential (E_T) of 20 volts is impressed across a series circuit consisting of two 5 ohm resistors. The total resistance of the circuit is equal to the sum of the two individual resistances, or 10 ohms. Using Ohm's Law the circuit current may be calculated as follows:

$$I = \frac{E_T}{R_T}$$

$$I = \frac{20}{10}$$

$$I = 2 \text{ amperes}$$

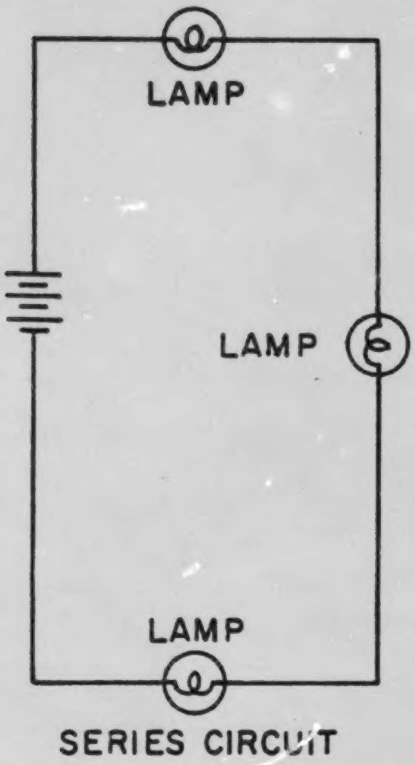
Knowing the size of the resistors to be 5 ohms each, and the current through the resistors to be 2 amperes, the voltage drops across the resistors can be calculated. The voltage (E_1) across R_1 is therefore:

$$E_1 = IR_1$$

$$E_1 = 2 \text{ amperes} \times 5 \text{ ohms}$$

$$E_1 = 10 \text{ volts}$$

Since R_2 is the same ohmic value as R_1 and carries the same current, the voltage drop



BE.58
Figure 4-18.—Series circuit.

Solution:

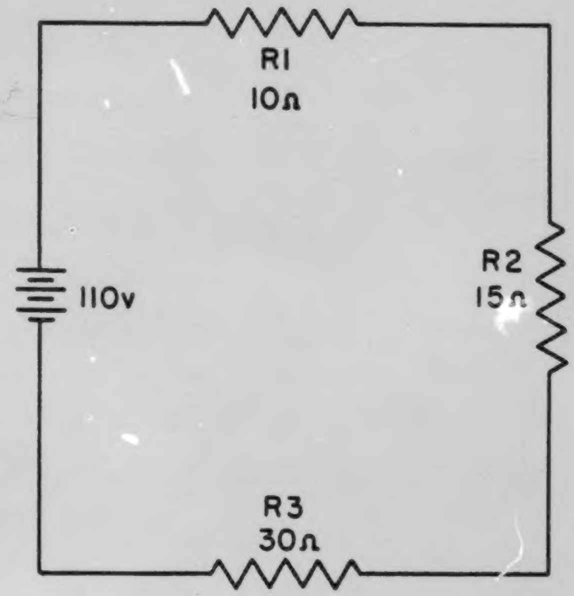
$$R_T = R_1 + R_2 + R_3$$

$$R_T = 10 + 15 + 30$$

$$R_T = 55 \text{ ohms}$$

In some circuit applications, the total resistance is known and the value of a circuit resistor has to be determined. Equation (4-11) can be transposed to solve for the value of the unknown resistance.

Example: The total resistance of a circuit containing three resistors is 40 ohms (fig. 4-20). Two of the circuit resistors are 10 ohms each. Calculate the value of the third resistor.



BE.59
Figure 4-19.—Solving for total resistance in a series circuit.

Given:

R_T = 40 ohms
R_1 = 10 ohms
R_2 = 10 ohms
R_3 = ?

Solution:

$$R_T = R_1 + R_2 + R_3 \tag{4-11}$$

Subtracting $(R_1 + R_2)$ from both sides of the equation

$$R_3 = R_T - R_1 - R_2$$

$$R_3 = 40 - 10 - 10$$

$$R_3 = 40 - 20$$

$$R_3 = 20 \text{ ohms}$$

CURRENT

Since there is but one path for current in a series circuit, the same current must flow required to move a unit charge from one point to another. As long as the source produces electric energy as rapidly as it is consumed in a resistance, the potential difference across the resistance will remain at a constant voltage. The value of this voltage is determined by the applied voltage and the proportional relationship of circuit resistances. The voltage drops that occur in a series circuit are in direct proportions to the resistance across which they appear. This is a result of having the same current flow through each resistor. Thus, the larger the resistor the larger will be the voltage drop across it.

POWER

Each of the resistors in a series circuit consumes power which is dissipated in the form of heat. Since this power must come from the source, the total power must be equal in amount to the power consumed by the circuit resistances. In a series circuit the total power is equal to the SUM of the powers dissipated by the individual resistors. Total power (P_T) is thus equal to:

$$P_T = P_1 + P_2 + P_3 + \ldots P_n \qquad (4\text{-}13)$$

Example: A series circuit consists of three resistors having values of 5 ohms, 10 ohms, and 15 ohms. Find the total power dissipation when 120 volts is applied to the circuit. (See figure 4-24.)

given:
R_1 = 5 ohms
R_2 = 10 ohms
R_3 = 15 ohms
E = 120 volts

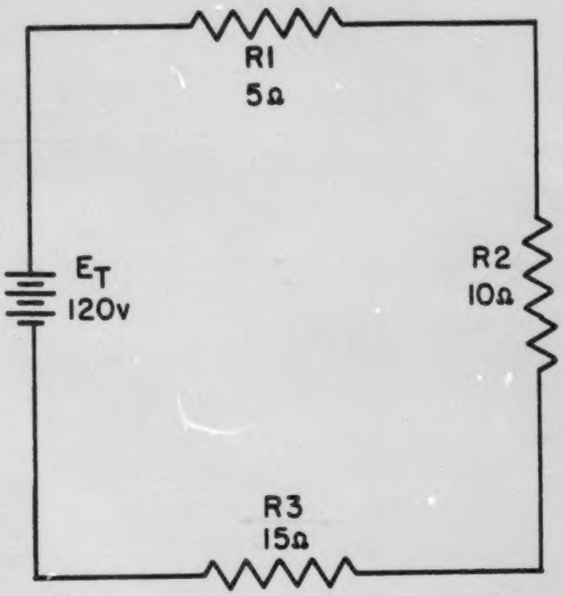
Solution: The total resistance is found first.

$$R_T = R_1 + R_2 + R_3 \qquad (4\text{-}11)$$

$$R_T = 5 + 10 + 15$$

$$R_T = 30 \text{ ohms}$$

Using total resistance and the applied voltage, the circuit current is calculated.



BE. 64

Figure 4-24.—Solving for total power in a series circuit.

$$I = \frac{E_T}{R_T}$$

$$I = \frac{120}{30}$$

$$I = 4 \text{ amperes}$$

Using the power formulas, the individual power dissipations can be calculated. For resistor R_1:

$$P_1 = I^2R_1 \qquad (4\text{-}6)$$

$$P_1 = (4)^2 5$$

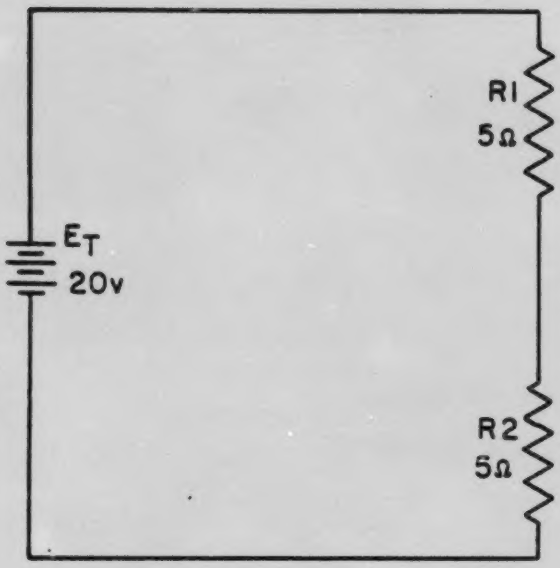
$$P_1 = 80 \text{ watts}$$

For R_2:

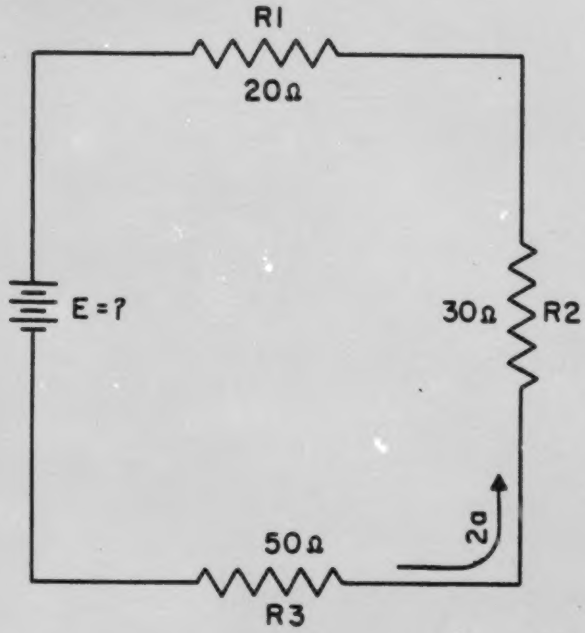
$$P_2 = I^2R_2 \qquad (4\text{-}6)$$

$$P_2 = (4)^2 10$$

$$P_2 = 160 \text{ watts}$$



BE.62
Figure 4-22.—Calculating total resistance in a series circuit.



BE.63
Figure 4-23.—Solving for applied voltage in a series circuit.

across R_2 is also equal to 10 volts. Adding these two 10 volt drops together gives a total drop of 20 volts exactly equal to the applied voltage. For a series circuit then:

$$E_T = E_1 + E_2 + E_3 \ldots E_n \qquad (4\text{-}12)$$

Example: A series circuit consists of three resistors having values of 20 ohms, 30 ohms, and 50 ohms respectively. Find the applied voltage if the current through the 30 ohm resistor is 2 amperes.

To solve the problem, a circuit diagram is first drawn and labeled as shown in figure 4-23.

Given:
$R_1 = 20$ ohms
$R_2 = 30$ ohms
$R_3 = 50$ ohms
$I = 2$ amperes

Solution: Since the circuit involved is a series circuit, the same 2 amperes of current flows through each resistor. Using Ohm's Law, the voltage drops across each of the three resistors can be calculated and are:

$E_1 = 40$ volts
$E_2 = 60$ volts
$E_3 = 100$ volts

Once the individual drops are known they can be added to find the total or applied voltage:

$$E_T = E_1 + E_2 + E_3 \qquad (4\text{-}12)$$

$$E_T = 40\text{v} + 60\text{v} + 100\text{v}$$

$$E_T = 200 \text{ volts}$$

NOTE: In using Ohm's Law, the quantities used in the equation MUST be taken from the SAME part of the circuit. In the above example the voltage across R_2 was computed using the current through R_2 and the resistance of R_2.

It must be emphasized that the potential difference across a resistor remains constant, for it is a measure of the amount of energy

By Ohm's Law the current is:

$$I = \frac{E_{bb}}{R_T}$$

$$I = \frac{90}{30}$$

$$I = 3 \text{ amperes}$$

The voltage (E_1) across R_1 is:

$$E_1 = IR_1$$

$$E_1 = 3 \text{ amperes} \times 5 \text{ ohms}$$

$$E_1 = 15 \text{ volts}$$

The voltage (E_2) across R_2 is:

$$E_2 = IR_2$$

$$E_2 = 3 \text{ amperes} \times 10 \text{ ohms}$$

$$E_2 = 30 \text{ volts}$$

The voltage (E_3) across R_3 is:

$$E_3 = IR_3$$

$$E_3 = 3 \text{ amperes} \times 15 \text{ ohms}$$

$$E_3 = 45 \text{ volts}$$

The power dissipated in R_1 is:

$$P_1 = I \times E_1$$

$$P_1 = 3 \text{ amperes} \times 15 \text{ volts}$$

$$P_1 = 45 \text{ watts}$$

The power dissipated in R_2 is:

$$P_2 = I \times E_2$$

$$P_2 = 3 \text{ amperes} \times 30 \text{ volts}$$

$$P_2 = 90 \text{ watts}$$

The power dissipated in R_3 is:

$$P_3 = I \times E_3$$

$$P_3 = 3 \text{ amperes} \times 45 \text{ volts}$$

$$P_3 = 135 \text{ watts}$$

The total power dissipated is:

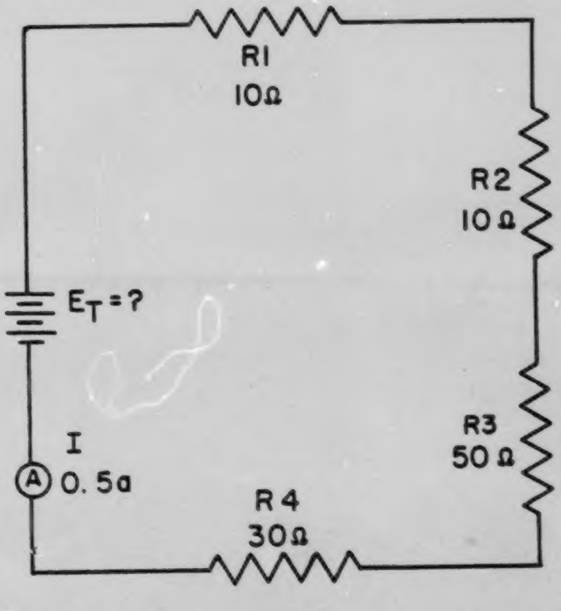
$$P_T = E_T \times I$$

$$P_T = 90 \text{ volts} \times 3 \text{ amperes}$$

$$P_T = 270 \text{ watts}$$

Example: Four resistors $R_1 = 10$ ohms, $R_2 = 10$ ohms, $R_3 = 50$ ohms, and $R_4 = 30$ ohms are connected in series across a battery. The current through the circuit is 0.5 amperes. (See figure 4-26.)

a. What is the battery voltage?
b. What is the voltage across each resistor?
c. What is the power expended in each resistor?
d. What is the total power?



BE.66

Figure 4-26.—Computing series circuit values.

For R_3:

$$P_3 = I^2R_3 \qquad (4\text{-}6)$$

$$P_3 = (4)^2 15$$

$$P_3 = 240 \text{ watts}$$

To obtain total power:

$$P_T = P_1 + P_2 + P_3 \qquad (4\text{-}13)$$

$$P_T = 80 + 160 + 240$$

$$P_T = 480 \text{ watts}$$

To check the answer the total power delivered by the source can be calculated:

$$P_{source} = I_{source} \times E_{source} \qquad (4\text{-}4)$$

$$P_{source} = 4 \text{ a.} \times 120 \text{ v.}$$

$$P_{source} = 480 \text{ watts}$$

Thus the total power is equal to the sum of the individual power dissipations.

RULES FOR SERIES D-C CIRCUITS

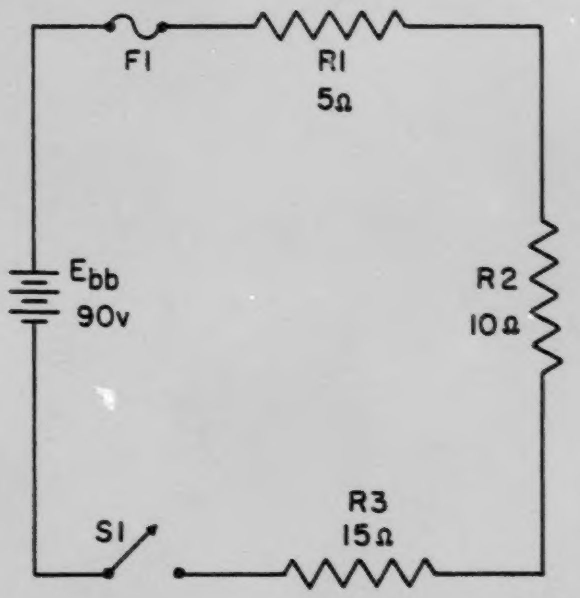
The important factors governing the operation of a series circuit are listed below. These factors have been set up as a group of rules so that they may be easily studied. These rules must be completely understood before the study of more advanced circuit theory is undertaken.

1. The same current flows through each part of a series circuit.
2. The total resistance of a series circuit is equal to the sum of the individual resistances.
3. The total voltage across a series circuit is equal to the sum of the individual voltage drops.
4. The voltage drop across a resistor in a series circuit is proportional to the size of the resistor.
5. The total power dissipated in a series circuit is equal to the sum of the individual power dissipations.

GENERAL CIRCUIT ANALYSIS

To establish a procedure for solving series circuits, the following sample problem will be solved.

Example: Three resistors of 5 ohms, 10 ohms, and 15 ohms are connected across a battery rated at 90 volts terminal voltage. Completely solve the circuit (fig. 4-25).



BE.65

Figure 4-25.—Solving for various values in a series circuit.

In solving the circuit the total resistance will be found first. Next, the circuit current will be calculated. Once the current is known the voltage drops and power dissipations can be calculated.

The total resistance is:

$$R_T = R_1 + R_2 + R_3$$

$$R_T = 5 \text{ ohms} + 10 \text{ ohms} + 15 \text{ ohms}$$

$$R_T = 30 \text{ ohms}$$

particular resistor. For exampler, to find the value of an unknown resistance, the voltage across and the current through that particular resistor must be used.

To find the value of a resistor:

$$R = \frac{E_R}{I_R}$$

To find the voltage drop across a resistor:

$$E_R = I_R \times R$$

To find current through a resistor:

$$I_R = \frac{E_R}{R}$$

KIRCHHOFF'S VOLTAGE LAW

In 1847 Kirchhoff extended the use of Ohm's Law by developing a simple concept concerning the voltages contained in a series circuit loop. Kirchhoff's Law is stated as follows.

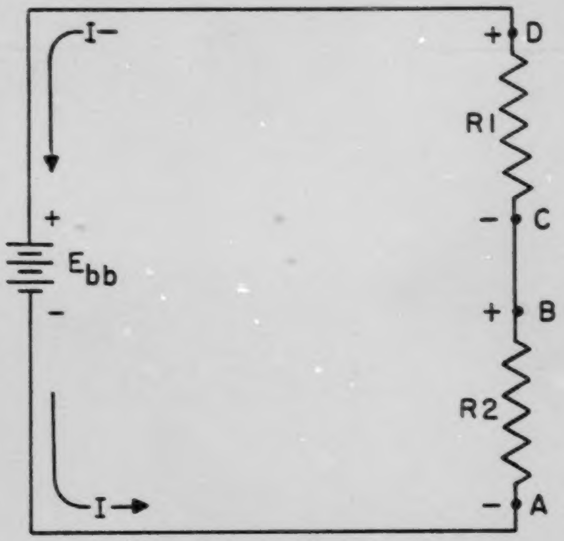
> The algebraic sum of the instantaneous emf's and voltage drops around any closed circuit loop is zero.

Through the use of Kirchhoff's Law, circuit problems can be solved which would be difficult and often impossible with only a knowledge of Ohm's Law. When the law is properly applied, an equation can be set up for a closed loop and the unknown circuit values may be calculated.

POLARITY OF VOLTAGE

To apply Kirchhoff's Voltage Law, the meaning of voltage POLARITY must be understood. In the circuit shown in figure 4-27 the current is seen to be flowing in a counterclockwise direction due to the arrangement of the battery source E_{bb}. Notice that the end of resistor R_1 into which the current flows is marked NEGATIVE (-). The end of R_1 at which the current leaves is marked POSITIVE (+). These polarity markings are used to show that the end of R_1 into which the current flows is at a higher negative potential than is the end of the resistor at which the current leaves. Point A is thus more negative than point B.

Point C, which is at the same potential as point B, is labeled negative. This is to indicate that point C, though positive with respect to point A, is more negative than point D. To say a point is positive (or negative), without stating what it is positive IN RESPECT TO, has no meaning.



BE.67

Figure 4-27.—Voltage polarities.

Kirchhoff's Voltage Law can be written as an equation as shown below:

$$E_a + E_b + E_c + \ldots E_n = 0 \qquad (4\text{-}14)$$

where E_a, E_b, etc., are the voltage drops and emf's around any closed circuit loop. To set up the equation for an actual circuit, the following procedure is used.

1. Assume a direction of current through the circuit. (Correct direction desirable but not necessary.)
2. Using assumed direction of current, assign polarities to all resistors through which the current flows.
3. Place correct polarities on any source included in the circuit.
4. Starting at any points in the circuit, trace around the circuit writing down the magnitude and polarity of the voltage across each component in succession. The polarity used is the sign AFTER the component is passed through. Stop

Given:

R_1 = 10 ohms

R_2 = 10 ohms

R_3 = 50 ohms

R_4 = 30 ohms

I = 0.5 ampere

Find:

$E_1 = ?$ $P_1 = ?$

$E_2 = ?$ $P_2 = ?$

$E_3 = ?$ $P_3 = ?$

$E_4 = ?$ $P_4 = ?$

$E_T = ?$ $P_T = ?$

Solution:

(a) $R_T = R_1 + R_2 + R_3 + R_4$

$R_T = 10 + 10 + 50 + 30 = 100$ ohms

$E_T = IR_T = 0.5 \times 100 = 50$ volts

(b) $E_1 = IR_1 = 0.5 \times 10 = 5$ volts

$E_2 = IR_2 = 0.5 \times 10 = 5$ volts

$E_3 = IR_3 = 0.5 \times 50 = 25$ volts

$E_4 = IR_4 = 0.5 \times 30 = 15$ volts

Check:

$E_T = E_1 + E_2 + E_3 + E_4$

$E_T = 5 + 5 + 25 + 15 = 50$ volts

(c) Power consumed in R_1 is:

$P_1 = IE_1 = 0.5 \times 5 = 2.5$ watts

$P_2 = IE_2 = 0.5 \times 5 = 2.5$ watts

$P_3 = IE_3 = 0.5 \times 25 = 12.5$ watts

$P_4 = IE_4 = 0.5 \times 15 = 7.5$ watts

(d) Total power

$P_T = P_1 + P_2 + P_3 + P_4$

$P_T = 2.5 + 2.5 + 12.5 + 7.5 = 25$ watts

Check:

$P_T = I_T{}^2 R_T = 0.5^2 \times 100 = 25$ watts

or:

$P_T = I_T E_T = 0.5 \times 50 = 25$ watts

or:

$$P_T = \frac{E_T{}^2}{R_T} = \frac{50^2}{100} = \frac{2500}{100} = 25 \text{ watts}$$

An important fact to keep in mind when applying Ohm's Law to a series circuit is to consider whether the values used are component values or total values. When the information available enables the use of Ohm's Law to find total resistance, total voltage and total current, total values must be inserted into the formula.

To find total resistance:

$$R_T = \frac{E_T}{I_T}$$

To find total voltage:

$$E_T = I_T \times R_T$$

To find total current:

$$I_T = \frac{E_T}{R_T}$$

NOTE: I_T is equal to I in a series circuit. However, the distinction between I_T and I in the formula should be noted. The reason being that future circuits may have several currents, and it will be necessary to differentiate between I_T and other currents.

To compute any quantity (E, I, R, or P) associated with a single given resistor, the values used in the formula must be obtained from that

Since E = IR, by substitution:

$$IR_2 + IR_1 - E_A + IR_3 = 0$$

Substituting values:

$$10I = 5I - 60 + 15I = 0$$

Combining like terms:

$$30I - 60 = 0$$

$$30I = 60$$

$$I = 2 \text{ amperes}$$

Since the current obtained in the above calculations is a positive 2 amperes, the assumed direction of current was correct. To show what happens if the incorrect direction of current is assumed, the problem will be solved as before but with the opposite direction of current. The circuit is redrawn showing the new direction of current and new polarities in figure 4-30.

Solution:

$$E_a + E_b + E_c + \ldots E_n = 0 \qquad (4\text{-}14)$$

Starting at point (A):

$$-E_2 - E_1 - E_A - E_3 = 0$$

$$-IR_2 - IR_1 - E_A - IR_3 = 0$$

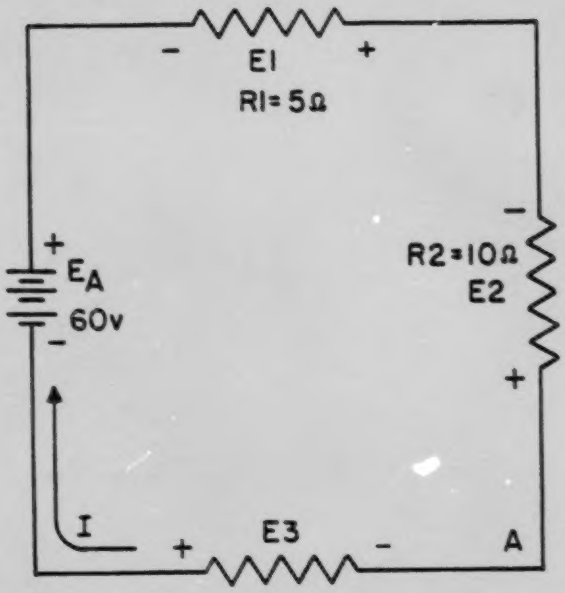
$$10I - 5I - 60 - 15I = 0$$

$$-30I - 60 = 0$$

$$-30I = 60$$

$$I = -2 \text{ amperes}$$

Notice that the AMOUNT of current is the SAME as before. Its polarity, however, is NEGATIVE. The negative polarity simply indicates the wrong direction of current was assumed. Should it be necessary to use this current in further calculations on the circuit, the negative polarity should be retained in the calculations.



BE.70

Figure 4-30.—Incorrect direction of assumed current.

SERIES AIDING AND OPPOSING SOURCES

In many practical applications a circuit may contain more than one source. Sources of emf that cause current to flow in the same direction are considered to be SERIES AIDING and their voltages add. Sources of emf that would tend to force current in opposite directions are said to be SERIES OPPOSING, and the effective source voltage is the difference between the opposing voltages. When two opposing sources are inserted into a circuit, current flow would be in a direction determined by the larger source. Examples of series aiding and opposing sources are shown in figure 4-31.

MULTIPLE SOURCE SOLUTIONS

A simple solution may be obtained for a multiple source circuit through the use of Kirchhoff's Voltage Law. In applying this method, the exact same procedure is used for the multiple source as was used above for the single source circuit. This is demonstrated by the following problem.

when reaching the point at which the trace was started.

5. Place these voltages with their polarities into equation (4-14) and solve for the desired quantity.

Example: Three resistors are connected across a 50 volt source. What is the voltage across the third resistor if the voltage drops across the first two resistors are 25 volts and 15 volts?

Solution: A diagram is first drawn as shown in figure 4-28. Next a direction of current is assumed as shown. Using this current, the polarity markings are placed at each end of each resistor and also on the terminals of the source. Starting at point A, trace around the circuit in the direction of current flow recording the voltage and polarity of each component. Starting at point A these voltages would be as follows:

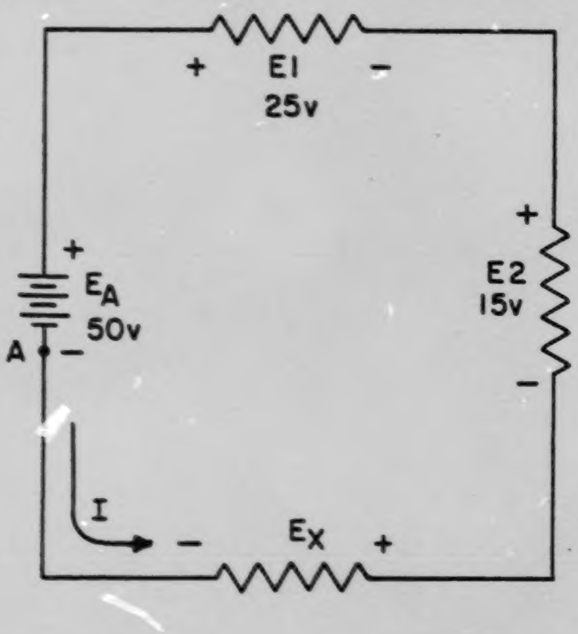


Figure 4-28.—Determining unknown voltage in a series circuit.

Basic formula:

$$E_a + E_b + E_c \dots E_n = 0 \qquad (4\text{-}14)$$

From the circuit:

$$(+E_x) + (+E_2) + (+E_1) + (-E_A) = 0$$

Substituting values from circuit:

$$E_x + 15 + 25 + 50 = 0$$

$$E_x - 10 = 0$$

$$E_x = 10 \text{ volts}$$

Thus, the unknown voltage (E_x) is found to be 10 volts.

Using the same idea as above, a problem can be solved in which the current is the unknown quantity.

Example: A circuit having a source voltage of 60 volts contains three resistors of 5 ohms, 10 ohms, and 15 ohms. Find the circuit current.

Solution: Draw and label the circuit (fig. 4-29). Establish a direction of current flow and assign polarities. Next, starting at any point, point (A) will be chosen in this example; write out the loop equation.

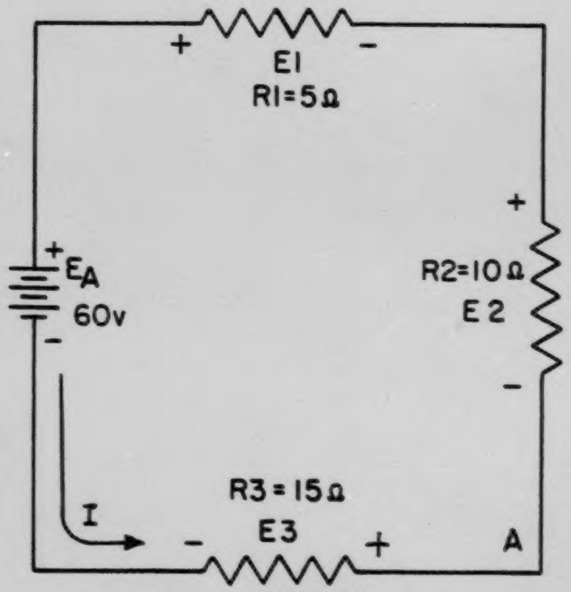
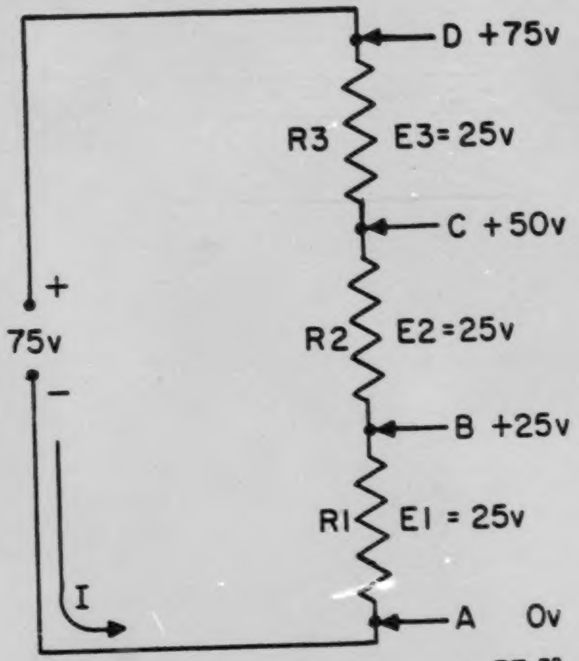


Figure 4-29.—Correct direction of assumed current.

Basic equation:

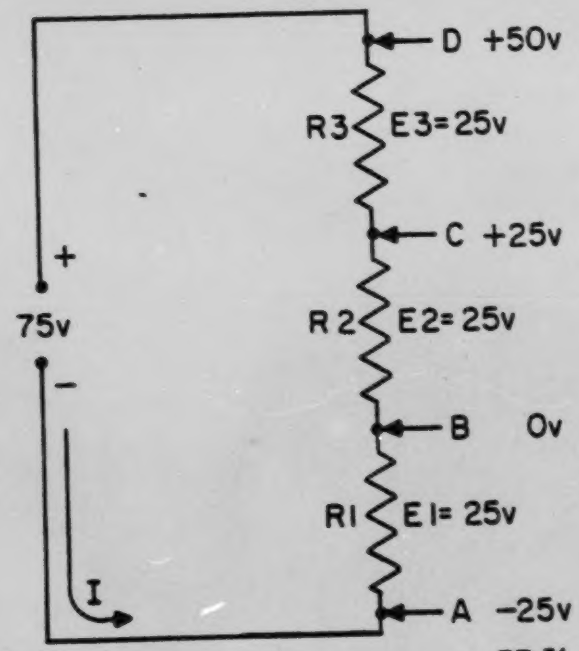
$$E_a + E_b + E_c + \dots E_n = 0 \qquad (4\text{-}14)$$

$$+E_2 + E_1 - E_A + E_3 = 0$$



BE.73

Figure 4-33.—Reference points in a series circuit.



BE.74

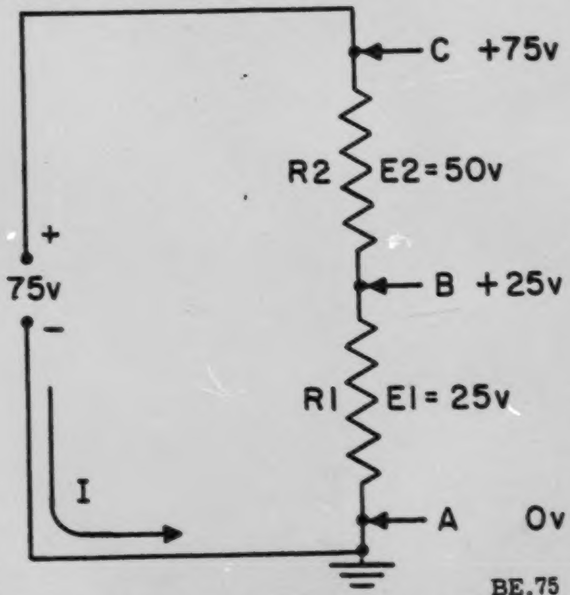
Figure 4-34.—Determining potentials with respect to a reference point.

If point B is used as the reference as in figure 4-34, point D would be positive 50 volts in respect to the new reference point B. The former reference point A is 25 volts negative in respect to point B.

GROUND

As in the previous circuit illustration, the reference point of a circuit is always considered to be at zero potential. Since the earth (ground) is said to be at a zero potential, the term GROUND is used to denote a common electrical point of zero potential. In figure 4-35, point A is the zero reference or ground and is symbolized as such.

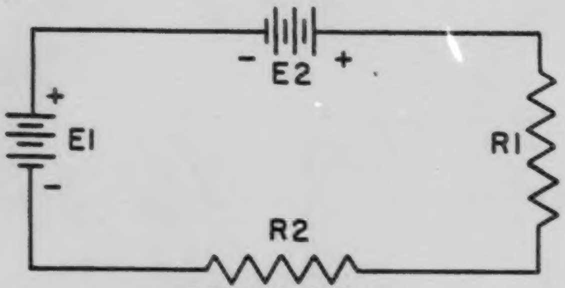
Point C is 75 volts positive and point B is 25 volts positive in respect to ground.



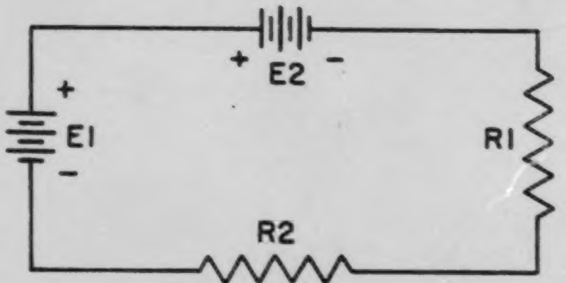
BE.75

Figure 4-35.—Use of ground symbols.

In many electrical/electronic equipments, the metal chassis is the common ground for the many electrical circuits. The value of ground is noted when considering its contribution to economy, simplification of schematics, and ease of measurement. When completing each electrical circuit, common points of a circuit at zero potential are connected directly to the metal chassis thereby eliminating a large amount of connecting wire. The electrons pass through the metal chassis (conductor) to reach other points of the circuit. An example of a grounded circuit is illustrated in figure 4-36.



SERIES AIDING



SERIES OPPOSING

BE. 71
Figure 4-31. —Aiding and opposing sources.

Example: Using Kirchhoff's Voltage equation, find the amount of current in the circuit shown in figure 4-32.

Solution: As before, a direction of current flow is assumed and polarity signs are placed on the drawing. The loop equation will be starting at point A.

Basic equation:

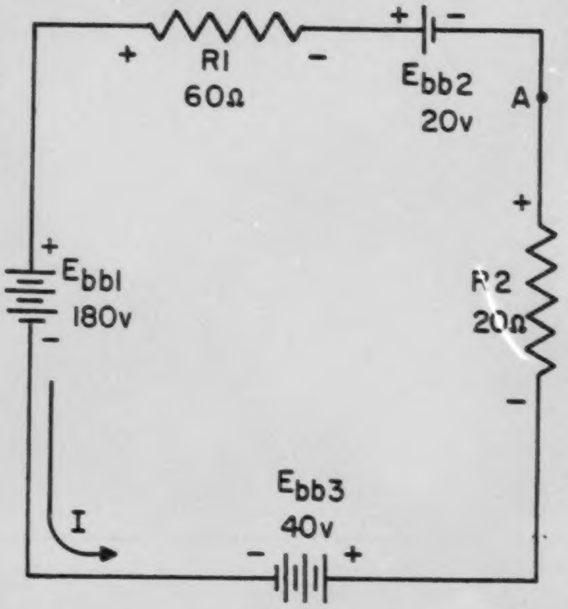
$$E_a + E_b + E_c + \ldots . E_n = 0 \qquad (4\text{-}14)$$

From the circuit:

$$E_{bb2} + E_1 - E_{bb1} + E_{bb3} + E_2 = 0$$
$$+ 20 + 60I - 180 + 40 + 20I = 0$$

Combining like terms:

$$+ 80I - 120 = 0$$
$$80I = 120$$
$$I = 1.5 \text{ amperes}$$

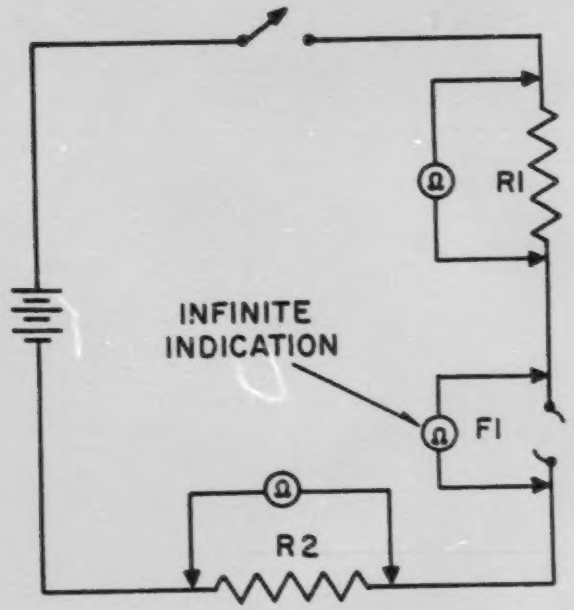


BE.72
Figure 4-32.—Solving for circuit current using Kirchhoff's voltage equation.

VOLTAGE REFERENCES

REFERENCE POINT

A reference point is an arbitrarily chosen point to which all other points are compared. In series circuits, any point can be chosen as a reference and the electrical potential at all other points can be determined in reference to the initial point. In the example of figure 4-33 point A shall be considered as the reference. Each series resistor in the illustrated circuit is of equal value; therefore, the applied voltage is equally distributed across each resistor. The potential at point B is 25 volts more positive than A. Points C and D are 50 volts and 75 volts respectively more positive than point A.



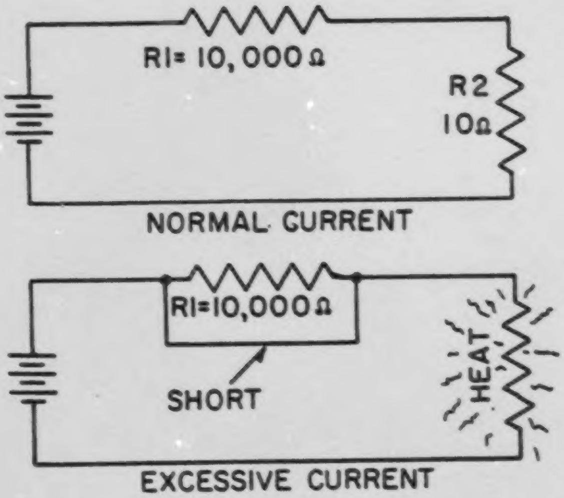
BE.78

Figure 4-38.—Ohmmeter readings in a series circuit.

In figure 4-39 a short is caused by improper wiring. Note the effect on current flow. Since the resistor has in effect been replaced with a piece of wire, practically all the current flows through the short and very little current flows through the resistor. Electrons flow through the short, a path of almost zero resistance and complete the circuit by passing through the 10-ohm resistor and the battery. The amount of current flow increases greatly because its resistive path has decreased from 10,010 ohms to 10 ohms. Due to the excessive current through the 10-ohm resistor, the increased heat dissipated by the resistor will destroy the component.

EFFECT OF SOURCE RESISTANCE ON VOLTAGE, POWER, AND EFFICIENCY

All sources of emf have some internal resistance that acts in series with the load resistance. The source resistance is generally indicated in circuit diagrams as a separate resistor connected in series with the source. Both the voltage and power made available to the load may be increased if the resistance of the source is reduced.



BE.79

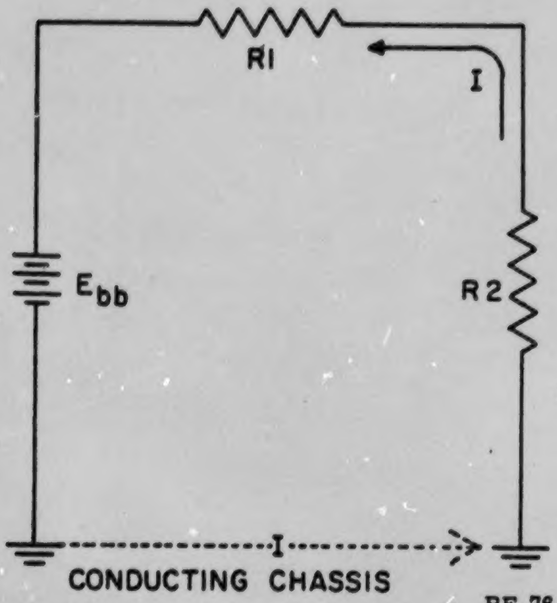
Figure 4-39. —Normal and short circuit conditions.

The effects of source resistance, R_s, on load voltage may be illustrated by the use of figure 4-40. In figure 4-40 (A), the circuit is open, and therefore a voltmeter connected across the battery will read the open-circuit voltage. In the case of a dry cell, the open-circuit voltage is 1.5 volts. In figure 4-40 (B), the cell is short-circuited through the ammeter, and a current of 30 amperes flows from the source. In this case the voltage of the cell is developed across the internal resistance of the cell. The internal resistance of the cell is therefore,

$$R_s = \frac{E_s}{I} = \frac{1.5}{30} = 0.05 \text{ ohm.}$$

If a load, R_L, of 0.10 ohm is connected to the circuit, as shown in figure 4-40 (C), the current, I, becomes

$$I = \frac{E_s}{R_t} = \frac{1.5}{0.15} = 10 \text{ amperes.}$$



BE.76
Figure 4-36.—Ground used as a conductor.

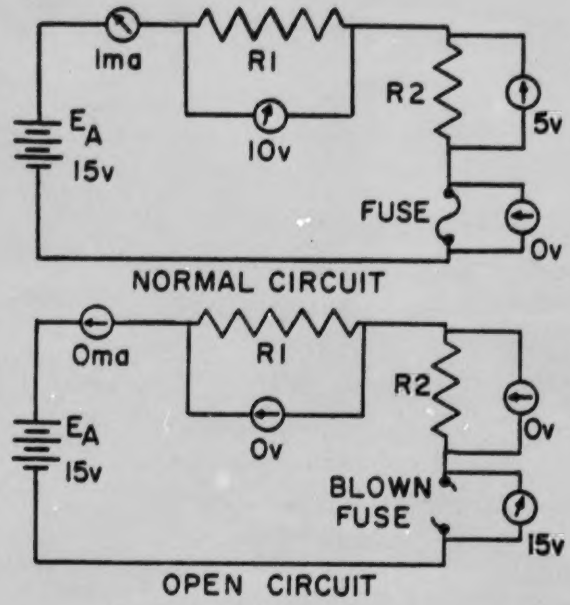
Most voltage measurements used to check proper circuit operation in electronic equipment are taken in respect to ground. One meter lead is attached to ground and the other meter lead is moved to various test points.

OPEN AND SHORT CIRCUITS

A circuit is said to be OPEN when a break exists in a complete conducting pathway. Although an open occurs any time a switch is thrown to deenergize a circuit, an open may also develop accidentally due to abnormal circuit conditions. To restore a circuit to proper operation, the open must be located and its cause determined.

Sometimes an open can be located visually by a close inspection of the circuit components. Defective components, such as burned out resistors and fuses can usually be discovered by this method. Others such as a break in wire covered by insulation, or the melted element of an enclosed fuse, are not visible to the eye. Under such conditions, the understanding of an open's effect on circuit conditions enables a technician to make use of a voltmeter or ohmmeter to locate the open component.

In figure 4-37, the series circuit consists of two resistors and a fuse. Notice the effects on circuit conditions when the fuse opens.



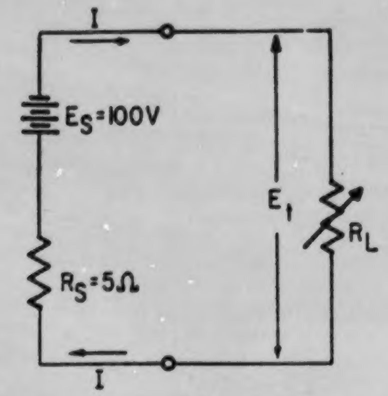
BE.77
Figure 4-37.—Normal and open circuit conditions.

Current ceases to flow; therefore, there is no longer a voltage drop across the resistors. Each end of the open conducting path becomes an extension of the battery terminals and the voltage felt across the open is equal to the applied voltage.

An open circuit, such as found in figure 4-37 could also have been located with an ohmmeter. However, when using an ohmmeter to check a circuit, it is important to first deenergize the circuit. The reason being that an ohmmeter has its own power source and would be damaged if connected to an energized circuit.

The ohmmeter used to check a series circuit would indicate the ohmic value of each resistance it is connected across. The open circuit due to its almost infinite resistance would cause no deflection on the ohmmeter as indicated by the illustration, figure 4-38.

A SHORT CIRCUIT is an accidental path of low resistance which passes an abnormal amount of current. A short circuit exists whenever the resistance of the circuit or the resistance of a part of a circuit drops in value to almost zero ohms. A short often occurs as a result of improper wiring or broken insulation.

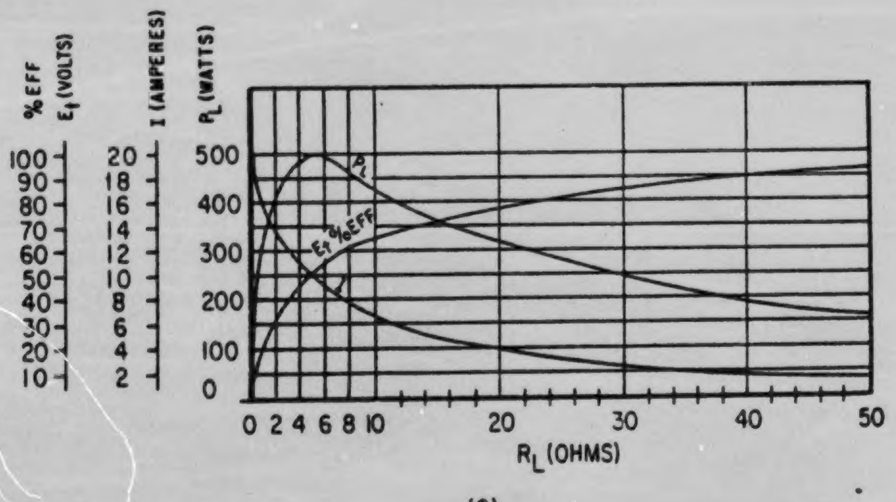


E_S = OPEN-CIRCUIT VOLTAGE OF SOURCE
R_S = INTERNAL RESISTANCE OF SOURCE
E_t = TERMINAL VOLTAGE
R_L = RESISTANCE OF LOAD
P_L = POWER USED IN LOAD
I = CURRENT FROM SOURCE
% EFF. = PERCENTAGE OF EFFICIENCY

(A)
CIRCUIT AND SYMBOL DESIGNATIONS

R_L	E_t	I	P_L	%EFF.
0	0	20	0	0
1	16.6	16.6	275.6	16.6
2	28.6	14.3	409	28.6
3	37.5	12.5	468.8	37.5
4	44.4	11.1	492.8	44.4
5	50	10	500	50
6	54.5	9.1	495.4	54.5
7	58.1	8.3	482.2	58.1
8	61.6	7.7	474.3	61.6
9	63.9	7.1	453.7	63.9
10	66	6.6	435.6	66
20	80	4	320	80
30	87	2.9	252	87
40	88	2.2	193.6	88
50	91	1.82	165	91

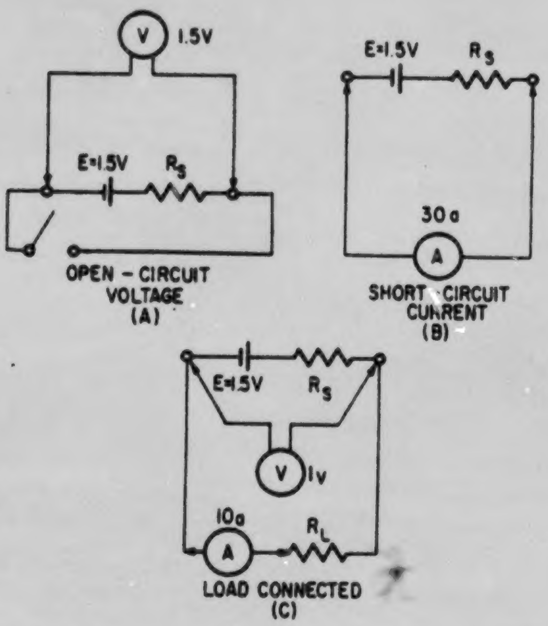
(B)
CHART



(C)
GRAPH

BE.81

Figure 4-41.—Effect of source resistance on power output.



BE.80

Figure 4-40.—Effect of source resistance on load voltage.

The voltage available at the load is

$$E_L = IR_L = 10 \times 0.1 = 1 \text{ volt.}$$

The voltage absorbed across the internal resistance of the cell is

$$IR_s = 10 \times 0.05 = 0.5 \text{ volt.}$$

Thus the effect of the internal resistance is to decrease the terminal voltage from 1.5 volts to 1 volt when the cell delivers 10 amperes to the load.

The effect of the source resistance on the power output of a d-c source may be shown by an analysis of the circuit in figure 4-41 (A). When the variable load-resistor, R_L, is set at the zero ohms position (equivalent to a short circuit) the current is limited only by the internal resistance, R_s, of the source. The short-circuit current, I, is determined as

$$I = \frac{E_s}{R_s} = \frac{100}{5} = 20 \text{ amperes}$$

This is the maximum current that may be drawn from the source. The terminal voltage across the short circuit is zero and all the voltage is absorbed within the terminal resistance of the source.

If the load resistance, R_L, is increased (the internal resistance remaining the same), the current drawn from the source will decrease. Consequently, the voltage drop across the internal resistance will decrease. At the same time, the terminal voltage applied across the load will increase and will approach a maximum as the current approaches zero.

The MAXIMUM POWER TRANSFER THEOREM says in effect that maximum power is transferred from the source to the load when the resistance of the load is equal to the internal resistance of the source. This theorem is illustrated in the tabular chart and the graph of figure 4-41 (B) and (C). When the load resistance is 5 ohms, thus matching the source resistance, the maximum power of 500 watts is developed in the load.

The efficiency of power transfer (ratio of output to input power) from the source to the load increases as the load resistance is increased. The efficiency approaches 100 percent as the load resistance approaches a relatively large value compared with that of the source, since less power is lost in the source. The efficiency of power transfer is only 50 percent at the maximum power transfer resistance of 5 ohms and approaches zero efficiency at relatively low values of load resistance compared with that of the source.

Thus the problem of high efficiency and maximum power transfer is resolved as a compromise somewhere between the low efficiency of maximum power transfer and the high efficiency of the high-resistance load. Where the amounts of power involved are large and the efficiency is important, the load resistance is made large relative to the source resistance so that the losses are kept small. In this case the efficiency will be high. Where the problem of matching a source to a load is of paramount importance, as in communications circuits, a strong signal may be more important than a high percentage of efficiency. In such cases, the efficiency of transmission will be only about 50 percent. However, the power of transmission will be the maximum of which the source is capable of supplying.

Express in powers of ten:

$$E_{R2} = (4.5 \times 10^{-3}) \times (30 \times 10^{3})$$

$$E_{R2} = 4.5 \times 30$$

Resultant:

$$E_{R2} = 135 \text{ v}$$

Therefore:

$$E_{bb} = 135 \text{ v}$$

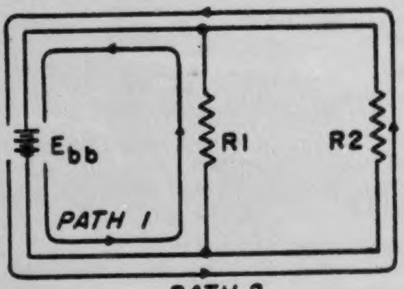
Having determined the voltage across one resistor (R_2) in a parallel circuit, the value of the source voltage (E_{bb}) and the potentials across any other resistors that may be connected in parallel with it are known (equations 5-1).

CURRENT DIVISION

The current in a circuit . . . . is inversely proportional to the circuit resistance. This fact, obtained from Ohm's law, establishes the relationship upon which the following discussion is developed.

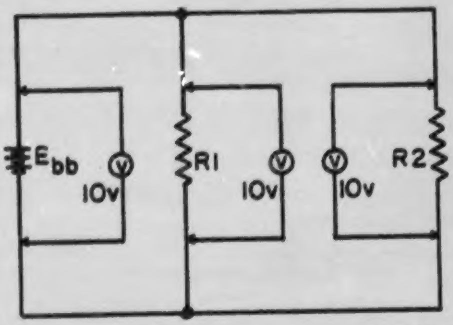
A single current flows in a series circuit. Its value is determined in part by the total resistance of the circuit. However, the source current in a parallel circuit divides among the available paths in relation to the value of the resistors in the circuit. Ohm's law remains unchanged. For a given voltage, current varies inversely with resistance.

The behavior of current in parallel circuits will be shown by a series of illustrations using example circuits with different values of resistance for a given value of applied voltage.



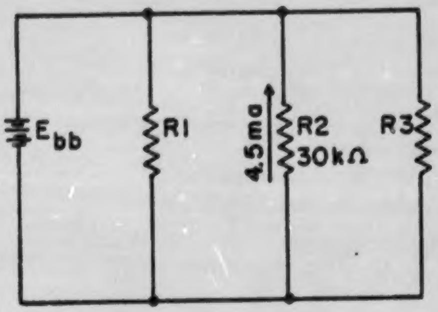
BE.82

Figure 5-1.—Example of a basic parallel circuit.



BE.83

Figure 5-2.—Voltage comparison in a parallel circuit.



BE.84

Figure 5-3.—Example problem parallel circuit.

Part (A) of figure 5-4 shows a basic series circuit. Here the total current must pass through the single resistor. The amount of current is determined as

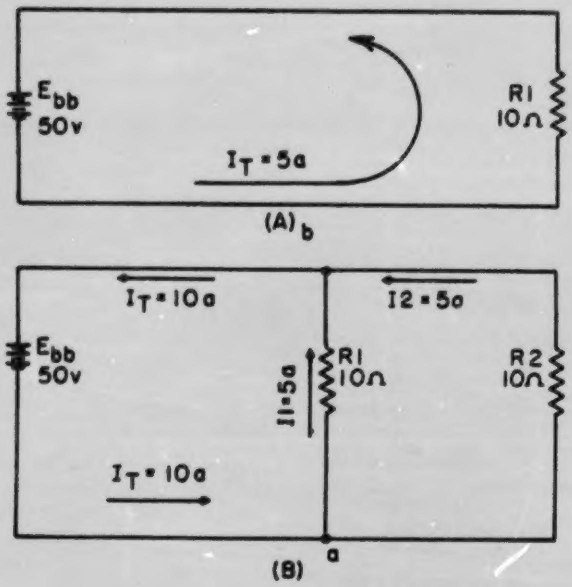
$$I_t = \frac{E_{bb}}{R_1} = \frac{50}{10} = 5 \text{ amperes}$$

Part (B) of figure 5-4 shows the same resistor (R_1) with a second resistor (R_2) of equal value connected in parallel across the voltage source. Applying the proper equation from Ohm's law, the current flow through each resistor is seen to be the same as through the single resistor in part (A). These individual currents are determined as follows:

$$I_{R1} = \frac{E_{bb}}{R_1} = \frac{50}{10} = 5 \text{ amperes}$$

$$I_{R2} = \frac{E_{bb}}{R_2} = \frac{50}{10} = 5 \text{ amperes}$$

However, it is apparent that if 5 amperes of current flows through each of the two resistors, there must be a total current of 10 amperes drawn from the source. The distribution of current in the simple parallel circuit shown in figure 5-4 (B) is as follows:



BE.35
Figure 5-4.—Analysis of current in parallel circuit.

The total current of 10 amperes leaves the negative terminal of the battery and flows to point a. Since point a is a connecting point for the two resistors, it is called a junction. At junction a the total current divides into two smaller currents of 5 amperes each. These two currents flow through their respective resistors and rejoin at junction b. The total current then flows from junction b back to the positive terminal of the source. Thus, the source supplies a total current of 10 amperes and each of the two equal resistors carries one-half the total current.

Each individual current path in the circuit of figure 5-4 (B) is referred to as a branch. Each branch will carry a current that is a portion of the total current. Two or more branches form a network.

From the foregoing observations, the characteristics of current in a parallel circuit can be expressed in terms of the following general equation

$$I_t = I_1 + I_2 + \ldots . I_n \qquad (5\text{-}2)$$

The analysis of current in parallel circuits is continued with the use of the following example circuits.

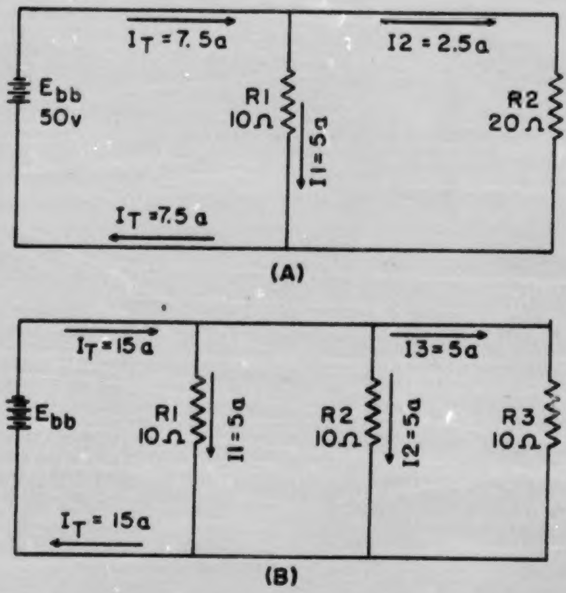
Compare part (A) of figure 5-5 with part (B) of the preceding example circuit in figure 5-4. Notice that doubling the value of the second branch resistor (R_2) has no effect on the current in the first branch (I_{R1}), but does reduce its own branch current (I_{R2}) to one-half its original value. The total circuit current drops to a value equal to the sum of the branch currents. These facts are verified as follows:

$$I_1 = \frac{E_{bb}}{R_1} = \frac{50}{10} = 5 \text{ amperes}$$

$$I_2 = \frac{E_{bb}}{R_2} = \frac{50}{20} = 2.5 \text{ amperes}$$

$$I_t = I_1 + I_2$$

$$I_t = 5 + 2.5 = 7.5 \text{ amperes}$$



BE.86
Figure 5-5.—Current behavior in parallel circuits.

Now compare the two circuits of figure 5-5. Notice that the sum of the ohmic values of the resistors in both circuits is equal and that the applied voltage is the same value. However, the total current in part (B) is twice the amount in part (A). It is apparent, therefore, that the manner in which resistors are connected in a circuit, as well as their actual ohmic value, affects the total current flow. This phenomenon will be illustrated in more detail in the discussion of resistance. The amount of current flow in the branch circuits and the total current in the circuit (fig. 5-5 (B)), are determined as follows:

$$I_1 = \frac{E_{bb}}{R_1} = \frac{50}{10} = 5 \text{ amperes}$$

$$I_2 = \frac{E_{bb}}{R_2} = \frac{50}{10} = 5 \text{ amperes}$$

$$I_3 = \frac{E_{bb}}{R_3} = \frac{50}{10} = 5 \text{ amperes}$$

$$I_t = I_1 + I_2 + 13$$

$$I_t = \frac{E_{bb}}{R_1} + \frac{E_{bb}}{R_2} + \frac{E_{bb}}{R_3}$$

$$I_t = \frac{50}{10} + \frac{50}{10} + \frac{50}{10} = 15 \text{ amperes}$$

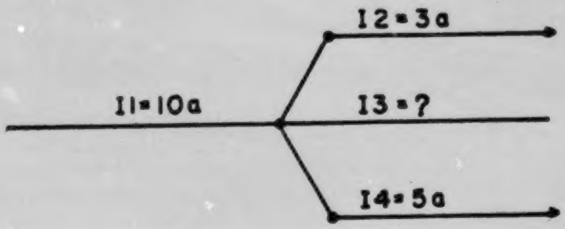
The division of current in a parallel network follows a definite pattern. This pattern is described by Kirchhoff's current law which is stated as follows:

The algebraic sum of the currents entering and leaving any junction of conductors is equal to zero. This law can be stated mathematically as

$$I_a + I_b + \dots\dots + I_n = 0 \qquad (5\text{-}3)$$

where I_a, I_b, etc., are the currents entering and leaving the junction. Currents entering the junction are assumed to be positive, and currents leaving the junction are considered negative. When solving a problem using equation (5-3), the currents must be placed into the equation with the proper polarity signs attached.

Example. Solve for the value of I_3 in figure 5-6.



BE.87

Figure 5-6.—Circuit for example problem.

Solution: First the currents are given proper signs.

$I_1 = +10$ amperes
$I_2 = -3$ amperes
$I_3 =$? amperes
$I_4 = -5$ amperes

these currents are placed into equation (5-3) with the proper signs as follows:

Basic equation:

$$I_a + I_b + \dots\dots I_n = 0 \qquad (5\text{-}3)$$

Substitution:

$$I_1 + I_2 + I_3 + I_4 = 0$$

$$(+10) + (-3) + (I_3) + (-5) = 0$$

Combining like terms:

$$I_3 + 2 = 0$$

$$I_3 = -2 \text{ amperes}$$

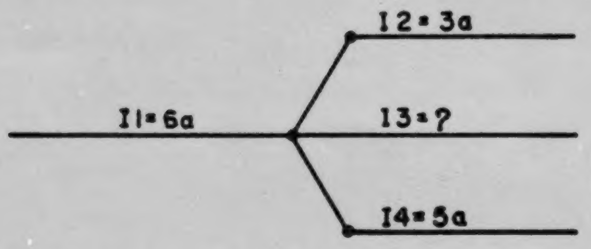
thus, I_3 has a value of 2 amperes, and the negative sign shows it to be a current leaving the junction.

Example. Using figure 5-7, solve for the magnitude and direction of I_3:

Solution:

$$I_a + I_b + \dots\dots I_n = 0 \qquad (5\text{-}3)$$

$$I_1 + I_2 + I_3 + I_4 = 0$$



BE. 88

Figure 5-7.—Circuit for example problem.

$$(+6a) + (-3a) + (I_3) + (-5a) = 0$$

$$I_3 - 2a = 0$$

$$I_3 = 2 \text{ amperes}$$

Thus, I_3 is 2 amperes, and its positive sign shows it to be a current entering the junction.

PARALLEL RESISTANCE

The preceding discussion of current introduced certain principles involving the characteristics and effects of resistance in parallel circuits. A detailed explanation of the characteristics of parallel resistances will be considered in this section. The explanation will commence with a simple parallel circuit. Various methods used to determine the total resistance in parallel circuits will be described.

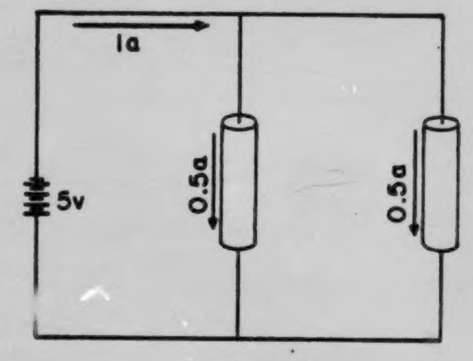
In the example diagram (fig. 5-8), two cylinders of conductive material having a resistance value of 10 ohms each are connected across a 5-volt battery. A complete circuit consisting of two parallel paths is formed and current will flow as shown.

Computing the individual currents shows that there is one-half an ampere of current flowing through each resistance. Accordingly, the total current flowing from the battery to the junction of the resistors, and returning from the resistors to the battery, is equal to 1 ampere. The total resistance of the circuit can be determined by substituting total values of voltage and current into the following equation. This equation is derived from Ohm's law.

$$R_t = \frac{E_t}{I_t}$$

$$R_t = \frac{5}{1} = 5 \text{ ohms}$$

This computation shows the total resistance to be 5 ohms, one-half the value of either of the two resistors.



BE.89

Figure 5-8.—Two equal resistors connected in parallel.

Since the total resistance of this parallel circuit is smaller than either of the two resistors, the term "total resistance" does not mean the sum of the individual resistor values. The total resistance of resistors in parallel is also referred to as equivalent resistance. In many texts the terms total resistance and equivalent resistances are used interchangeably.

There are several methods used to determine the equivalent resistance of parallel circuits. The most appropriate method for a particular circuit depends on the number and value of the resistors. For the circuit described above, the following simple equation is used:

$$R_{eq} = \frac{R}{N}$$

where

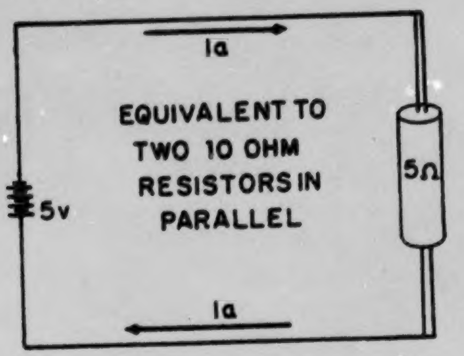
R_{eq} = equivalent parallel resistance

R = ohmic value of one resistor

N = number of resistors

This equation is valid for any number of equal value parallel resistors.

An understanding of why the equivalent resistance of two parallel resistors is smaller than the resistance of either of the two resistors can be gained by an examination of figure 5-8. The two 10-ohm cylinders have fixed equal volumes. If the cylinders were combined into one cylinder as shown in figure 5-9, the volume would double. If the same length is retained and the volume is doubled, the cross-sectional area will double. When the cross-sectional area of a material is increased, the resistance is decreased proportionately.



BE. 90

Figure 5-9.—Equivalent parallel circuit.

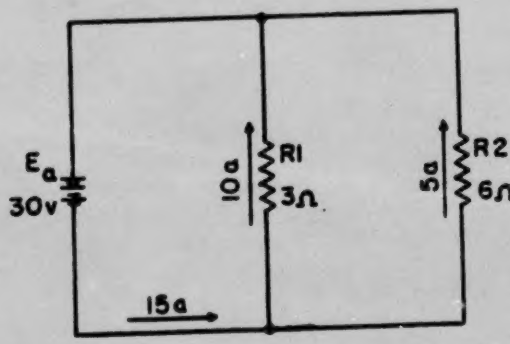
Since, in this case, the cross-sectional area is two times the original area, the resistance is one-half the former value. Therefore, when two equal value resistors are connected in parallel, they present a total resistance equivalent to a single resistor of one-half the value of either of the original resistors.

Example. Four 40-ohm resistors are connected in parallel. What is their equivalent resistance?

Solution:

$$R_{eq} = \frac{R}{N} = \frac{40}{4} = 10 \text{ ohms}$$

Circuits containing parallel resistance of unequal value will now be considered. Refer to example circuit in figure 5-10.



BE. 91

Figure 5-10.—Example circuit with unequal parallel resistors.

Given:

$$R_1 = 3\Omega,\ R_2 = 6\Omega,\ E_a = 30\text{v}$$

Known:

$I_1 = 10$ amperes, $I_2 = 5$ amperes, $I_t = 15$ amperes.

Determine:

$$R_{eq} = ?$$

Solution:

$$R_{eq} = \frac{E_a}{I_t}$$

$$R_{eq} = \frac{30}{15} = 2 \text{ ohms}$$

Notice that the equivalent resistance of two ohms is less than the value of either branch resistor. In parallel circuits the equivalent resistance will always be smaller than the resistance of any branch.

RECIPROCAL METHOD

Many circuits are encountered in which resistors of unequal value are connected in parallel. It is therefore desirable to develop a formula which can be used to compute the equivalent resistance of two or more unequal parallel resistors. This equation can be derived as follows:

Given:

$$I_t = I_1 + I_2 + \ldots\ldots I_n \qquad (5\text{-}2)$$

Substituting $\frac{E}{R}$ for I gives:

$$\frac{E_t}{R_t} = \frac{E_1}{R_1} + \frac{E_2}{R_2} + \ldots\ldots\ldots \frac{E_n}{R_n}$$

Since in a parallel circuit $E_t = E_1 = E_2 = E_n$

$$\frac{E}{R_t} = \frac{E}{R_1} + \frac{E}{R_2} + \ldots\ldots\ldots \frac{E}{R_n}$$

Dividing both sides by E:

$$\frac{E}{E\,R_t} = \frac{E}{E\,R_1} + \frac{E}{E\,R_2} + \ldots\ldots \frac{E}{E\,R_n}$$

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots\ldots \frac{1}{R_n}$$

Taking the reciprocal of both sides:

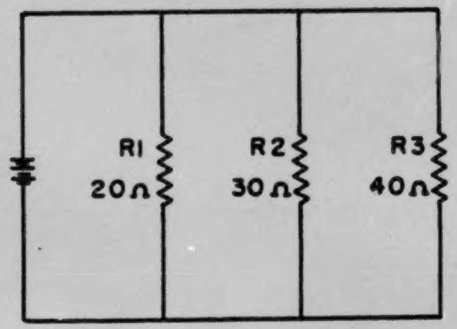
$$\frac{1}{\frac{1}{R_t}} = \frac{1}{\frac{1}{R_1}+\frac{1}{R_2}+\ldots\ldots\frac{1}{R_n}}$$

Simplifying:

$$R_t = \frac{1}{\frac{1}{R_1}+\frac{1}{R_2}+\ldots\ldots\ldots\frac{1}{R_n}}$$

This formula is called "the reciprocal of the sum of the reciprocals" and is the one normally used to solve for the equivalent resistance of a number of parallel resistors.

Example. Given three parallel resistors of 20 ohms, 30 ohms, and 40 ohms; find the equivalent resistance using the reciprocal equation. (See fig. 5-11.)



BE.92

Figure 5-11.—Example parallel circuit with unequal branch resistors.

Solution:

Select the proper equation:

$$R_{eq} = \frac{1}{\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}}$$

Substitute:

$$R_{eq} = \frac{1}{\frac{1}{20}+\frac{1}{30}+\frac{1}{40}}$$

Find LCD:

$$R_{eq} = \frac{1}{\frac{6}{120}+\frac{4}{120}+\frac{3}{120}} = \frac{1}{\frac{13}{120}}$$

Invert:

$$R_{eq} = \frac{120}{13} = 9.23 \text{ ohms}$$

Some parallel circuit problems can be solved more conveniently by considering the ease with which current can flow. The degree to which a circuit permits or conducts current is called the conductance (G) of the circuit. The unit of conductance is the MHO, which is ohms spelled backwards. The conductance of a circuit is the reciprocal of the resistance. The conductance can therefore be found using the following formula:

$$G = \frac{1}{R}$$

also:

$$R = \frac{1}{G}$$

In a parallel circuit, the total conductance is equal to the sum of the individual branch conductances. As an equation:

$$G_t = G_1 + G_2 + \ldots\ldots\ G_n \qquad (5\text{-}6)$$

Example: Determine the equivalent (total) resistance of the circuit shown in the preceding example (fig. 5-11), using the conductance method.

Solution:

$$G_1 = \frac{1}{R_1} = \frac{1}{20} = 0.050 \text{ mho}$$

$$G_2 = \frac{1}{R_2} = \frac{1}{30} = 0.033 \text{ mho}$$

$$G_3 = \frac{1}{R_3} = \frac{1}{40} = 0.025 \text{ mho}$$

$$G_t = G_1 + G_2 + G_3 \qquad (5\text{-}6)$$

$$G_t = 0.050 + 0.033 + 0.025 = 0.108 \text{ mho}$$

Since:

$$R_t = \frac{1}{G_t}$$

$$R_t = \frac{1}{0.108} = 9.25 \text{ ohms}$$

The value of equivalent resistance determined by the conductance method is almost identical to the value determined by the reciprocal of the sum of the reciprocals methods.

PRODUCT OVER THE SUM

A convenient formula for finding the equivalent resistance of two parallel resistors can be derived from equation (5-5) as shown below:

$$R_t = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} \qquad (5\text{-}5)$$

Finding the LCD:

$$R_t = \frac{1}{\frac{R_2 + R_1}{R_1 \times R_2}}$$

Taking the reciprocal:

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$

This equation, called the product over the sum formula, is used so frequently it should be committed to memory.

Example. What is the equivalent resistance of a 20 ohm and a 30 ohm resistor connected in parallel?

Given:

$R_1 = 20$

$R_2 = 30$

Find:

$R_{eq} = ?$

Solution:

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$R_t = \frac{20 \times 30}{20 + 30}$$

$$R_t = 12 \text{ ohms}$$

PARALLEL CIRCUIT REDUCTION

In the study of electricity, it is often necessary to resolve a complex circuit into a simpler form. Any complex circuit consisting of resistances can be reduced to a basic equivalent circuit containing the source and total resistance. This process is called reduction to an equivalent circuit. An example of circuit reduction is shown in figure 5-12.

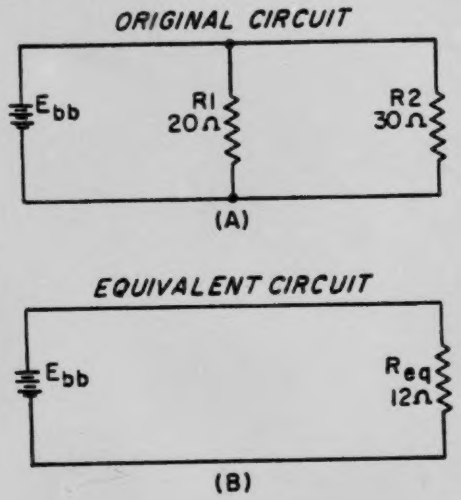


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Figure 5-12.—Parallel circuit with equivalent circuit.

The circuit shown in figure 5-12 (A) is reduced to the simple circuit shown in (B).

COMPUTING TOTAL POWER

Power computations in a parallel circuit are essentially the same as those used for the series circuit. Since power dissipation in resistors consists of a heat loss, power dissipations are additive regardless of how the resistors are connected in the circuit. The total power dissipated is equal to the sum of the powers dissipated by the individual resistors. Like the series circuit, the total power consumed by the parallel circuit is

$$P_t = P1 + P2 + \ldots\ldots P_n \qquad (4\text{-}13)$$

Example. Find the total power consumed by the circuit in figure 5-13.

Solution:

$$P_{R1} = E_{bb} \times I_{R1}$$

$$P_{R1} = 50 \times 5$$

$P_{R1} = 250\text{ w}$

$P_{R2} = E_{bb} \times I_{R2}$

$P_{R2} = 50 \times 2$

$P_{R2} = 100\text{ w}$

$P_{R3} = E_{bb} \times I_{R3}$

$P_{R3} = 50 \times 1$

$P_{R3} = 50\text{ w}$

$P_t = P_1 + P_2 + P_3$

$P_t = 250 + 100 + 50$

$P_t = 400\text{ w}$

Note that the power dissipated in the branch circuits is determined in the same manner as the power dissipated by individual resistors in a series circuit. The total power (P_t) is then obtained by summing up the powers dissipated in the branch resistors using equation (4-13).

Since, in the example shown in figure 5-13, the total current is known, the total power could be determined by the following method:

$P_t = E_{bb} \times I_t$

$P_t = 50\text{v} \times 8\text{a}$

$P_t = 400\text{ w}$

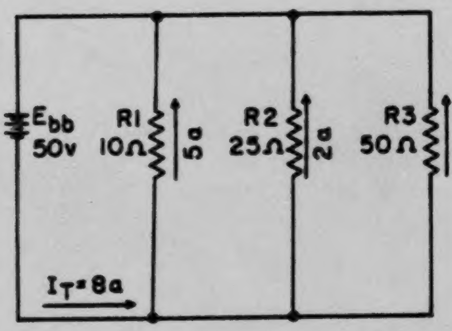

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Figure 5-13.—Example parallel circuit.

Rules for solving parallel d-c circuits are as follows:

1. The same voltage exists across each branch of a parallel circuit and is equal to the source voltage.
2. The current through a branch of a parallel network is inversely proportional to the amount of resistance of the branch.
3. The total current of a parallel circuit is equal to the sum of the currents of the individual branches of the circuit.
4. The total resistance of a parallel circuit is equal to the reciprocal of the sum of the reciprocals of the individual resistances of the circuit.
5. The total power consumed in a parallel circuit is equal to the sum of the power consumption of the individual resistances.

TYPICAL PROBLEMS IN PARALLEL CIRCUITS

Problems involving the determination of resistance, voltage, current, and power in a parallel circuit are solved as simply as in a series circuit. The procedure is the same—(1) draw a circuit diagram, (2) state the values given and the values to be found, (3) state the applicable equations, and (4) substitute the given values and solve for the unknown.

For example, the parallel circuit of figure 5-14 consists of 2 branches (a and b). Branch a consists of 3 lamps in parallel. Their ratings are L_1 = 50 watts, L_2 = 25 watts, and L_3 = 75 watts. Branch b also has 3 lamps in parallel with ratings of L_4 = 150 watts, L_5 = 200 watts, and L_6 = 250 watts. The source voltage is 100 volts.

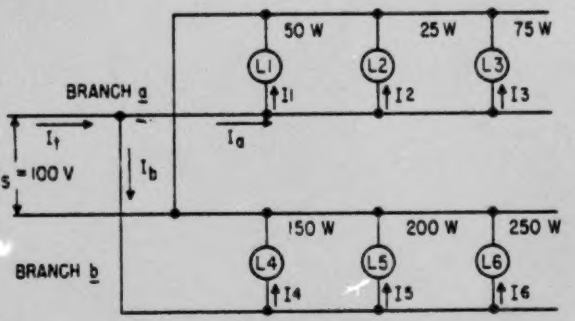

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Figure 5-14.—Typical parallel circuit.

Problem:

1. Find the current in each lamp.
2. Find the resistance of each lamp.
3. Find the current in branch a.
4. Find the current in branch b.
5. Find the total circuit current.
6. Find the total circuit resistance.
7. Find the total power supplied to the circuit.
8. Check 7 by a separate calculation.

Solution:

1. The current in L_1 is $I = \frac{P}{E} = \frac{50}{100} =$ 0.50 ampere.

   The current in L_2 is $\frac{25}{100} = 0.25$ ampere.

   The current in L_3 is $\frac{75}{100} = 0.75$ ampere.

   The current in L_4 is $\frac{150}{100} = 1.50$ amperes.

   The current in L_5 is $\frac{200}{100} = 2.00$ amperes.

   The current in L_6 is $\frac{250}{100} = 2.5$ amperes.

2. The resistance of L_1 is $R = \frac{E}{I} = \frac{100}{0.5} =$ 200 ohms.

   The resistance of L_2 is $\frac{100}{0.25} = 400$ ohms.

   The resistance of L_3 is $\frac{100}{0.75} = 133$ ohms.

   The resistance of L_4 is $\frac{100}{1.5} = 66.7$ ohms.

   The resistance of L_5 is $\frac{100}{2.0} = 50$ ohms.

   The resistance of L_6 is $\frac{100}{2.5} = 40$ ohms.

3. The current in branch a is

   $I_1 + I_2 + I_3 = 0.5 + 0.25 + 0.75 = 1.5$ amperes

4. The current in branch b is

   $I_4 + I_5 + I_6 = 1.5 + 2.0 + 2.5 = 6.0$ amperes

5. The total circuit current is

   $I_a + I_b = 1.5 + 6.0 = 7.5$ amperes

6. The total circuit resistance is

   $$R_t = \frac{E}{I_t} = \frac{100}{7.5} = 13.3 \text{ ohms}$$

7. The total power supplied to the circuit is:

   50w + 25w + 75w + 150w + 200w + 250w = 750 watts

8. The total power is also equal to

   $P_t = EI_t = 100 \times 7.5 = 750$ watts

SERIES-PARALLEL COMBINATIONS

In the preceding discussions, series and parallel d-c circuits have been considered separately. However, the technician will seldom encounter a circuit that consists solely of either type of circuit. Most circuits consist of both series and parallel elements. A circuit of this type will be referred to as a combination circuit. The solution of a combination circuit is simply a matter of application of the laws and rules discussed prior to this point.

SOLVING A COMBINATION CIRCUIT

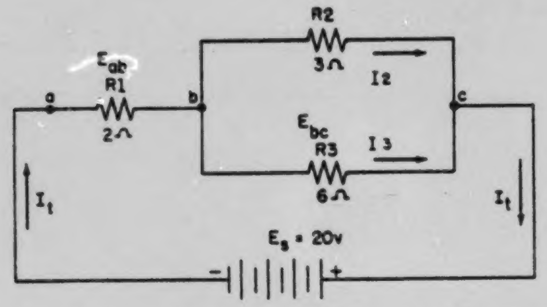
At least three resistors are required to form a combination circuit. Two basic series-parallel circuits are shown in figure 5-15. In figure 5-15 (A), R_1 is connected in series with the parallel combination made up of R_2 and R_3.

The total resistance (R_t) of figure 5-15 (A) is determined in two steps. First, the equivalent resistance of the parallel combination of R_2 and R_3 is determined as follows:

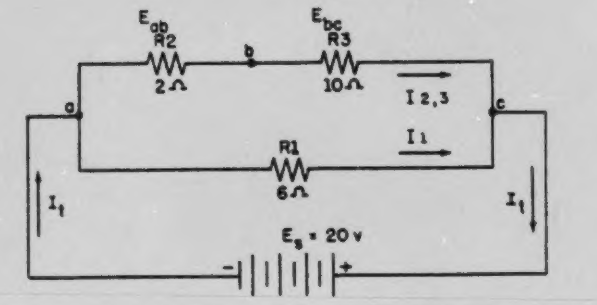
$$R_{2,3} = \frac{R_2 R_3}{R_2 + R_3} = \frac{3 \times 6}{3 + 6} = \frac{18}{9} = 2 \text{ ohms}$$

The sum of $R_{2,3}$ and R_1— that is, R_t — is

$$R_t = R_{2,3} + R_1 = 2 + 2 = 4 \text{ ohms}$$



R1 IN SERIES WITH PARALLEL COMBINATION OF R2 AND R3
(A)



R1 IN PARALLEL WITH THE SERIES COMBINATION OF R2 & R3
(B)

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Figure 5-15.—Compound circuits—series-parallel connections.

If the total resistance (R_t) and the source voltage (E_s) are known, the total current (I_t) may be determined by Ohm's law. Thus, in figure 5-15 (A),

$$I_t = \frac{E_s}{R_t} = \frac{20}{4} = 5 \text{ amperes}$$

If the values of the various resistors and the current through them are known, the voltage drops across the resistors may be determined by Ohm's law. Thus,

$$E_{ab} = I_t R_1 = 5 \times 2 = 10 \text{ volts}$$

and

$$E_{bc} = I_t R_{2,3} = 5 \times 2 = 10 \text{ volts}$$

According to Kirchhoff's voltage law, the sum of the voltage drops around the closed circuit is equal to the source voltage. Thus,

$$E_{ab} + E_{bc} = E_s$$

or

$$10 + 10 = 20 \text{ volts}$$

If the voltage drop (E_{bc}) across $R_{2,3}$—that is, the drop between points b and c—is known, the current through the individual branches may be determined as follows:

$$I_2 = \frac{E_{bc}}{R_2} = \frac{10}{3} = 3.333 \text{ amperes}$$

and

$$I_3 = \frac{E_{bc}}{R_3} = \frac{10}{6} = 1.666 \text{ amperes}$$

According to Kirchhoff's current law, the sum of the currents flowing in the individual parallel branches is equal to the total current. Thus,

$$I_2 + I_3 = I_t$$

or

$$3.333 + 1.666 = 5 \text{ amperes (approx)}$$

The total current flows through R_1; and at point b it divides between the two branches in inverse proportion to the resistance of each branch. Twice as much current goes through R_2 as through R_3 because R_2 has one-half the resistance of R_3. Thus, 3.333, or two-thirds of 5 amperes flows through R_2; and 1.666, or one-third of 5 amperes flows through R_3.

In figure 5-15 (B), R_1 is in parallel with series combination of R_2 and R_3. The total resistance (R_t) is determined in two steps. First, the sum of the resistance of R_2 and R_3—that is, $R_{2,3}$—is determined as follows:

$$R_{2,3} = R_2 + R_3 = 2 + 10 = 12 \text{ ohms}$$

Second, the total resistance (R_t) is the result of combining $R_{2,3}$ in parallel with R_1, or

$$R_t = \frac{R_{2,3}R_1}{R_{2,3} + R_1} = \frac{12 \times 6}{12 + 6} = 4 \text{ ohms}$$

If the total resistance (R_t) and the source voltage (E_s) are known, the total current (I_t) may be determined by Ohm's law. Thus, in figure 5-15 (B),

$$I_t = \frac{E_s}{R_t} = \frac{20}{4} = 5 \text{ amperes}$$

A portion of the total current flows through the series combination of R_2 and R_3 and the remainder flows through R_1. Because current varies inversely with the resistance, two-thirds of the total current flows through R_1 and one-third flows through the series combination of R_2 and R_3, since R_1 is one-half of $R_2 + R_3$.

The source voltage (E_s) is applied between points a and c, and therefore the current I_1 through R_1 is

$$I_1 = \frac{E_s}{R_1} = \frac{20}{6} = 3.333 \text{ amperes}$$

and the current, $I_{2,3}$, through $R_{2,3}$ is

$$I_{2,3} = \frac{E_s}{R_{2,3}} = \frac{20}{12} = 1.666 \text{ amperes}$$

According to Kirchhoff's current law the sum of the individual branch currents is equal to the total current, or

$$I_t = I_1 + I_{2,3}$$

$$5 = 3.333 + 1.666 \text{ (approx)}$$

Combination circuits may be made up of a number of resistors arranged in numerous series and parallel combinations. In more complicated circuits, special theorems, rules, and formulas are used. These are based on Ohm's Law and provide faster solutions for particular applications. Series formulas are applied to the series parts of the circuit, and parallel formulas are applied to the parallel parts. For example, in figure 5-16, the total resistance (R_t) may be obtained in three logical steps.

First, R_3, R_4, and R_5 in figure 5-16 (A), are in series (there is only one path for current) and may be combined in figure 5-16 (B), to give the resistance, R_s, of the three resistors. Thus,

$$R_s = R_3 + R_4 + R_5 = 5 + 9 + 10 = 24 \text{ ohms}$$

and it is now in parallel with R_2 (because they both receive the same voltage).

The combined resistance of R_s in parallel with R_2 is

$$R_{s,2} = \frac{R_2 R_s}{R_2 + R_s} = \frac{8 \times 24}{8 + 24} = 6 \text{ ohms}$$

as in the figure 5-16 (C).

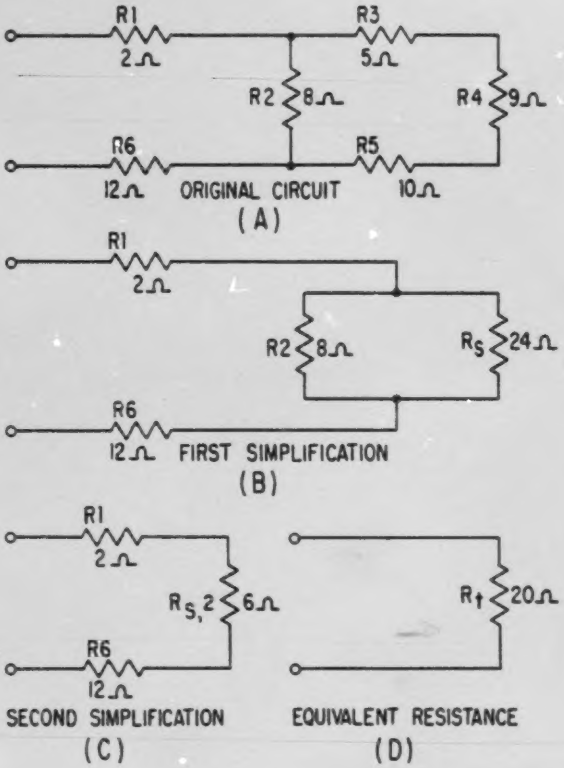

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Figure 5-16.—Solving total resistance in a compound circuit.

Third, the total resistance (R_t) is determined by combining resistors R_1 and R_6 with $R_{s,2}$ as

$$R_t = R_1 + R_6 + R_{s,2} = 2 + 12 + 6 = 20 \text{ ohms}$$

Other compound circuits may be solved in a similar manner. For example, in figure 5-17, the total resistance (R_t) may be found by simplifying the circuit in successive steps beginning with the resistance, R_1 and R_2. Thus,

$$R_{1,2} = \frac{R_1 R_2}{R_1 + R_2} = \frac{3 \times 6}{3 + 6} = \frac{18}{9} = 2 \text{ ohms}$$

and it is in series with R_3.

The resistances, $R_{1,2}$ and R_3, are added to give the resultant resistance, $R_{1,2,3}$. Thus,

$$R_{1,2,3} = R_{1,2} + R_3 = 2 + 4 = 6 \text{ ohms}$$

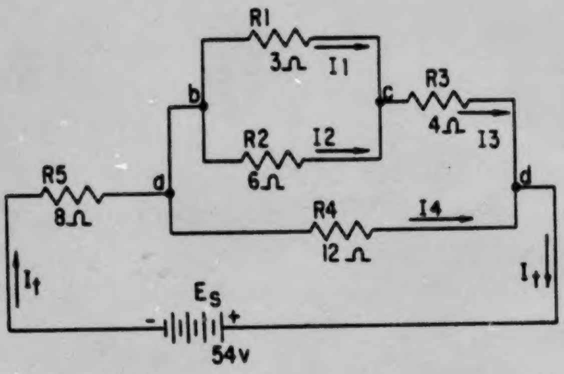

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Figure 5-17.—Compound circuit for solving resistance, voltage, current, and power.

$R_{1,2,3}$ is in parallel with R_4. The combined resistance, $R_{1,2,3,4}$, is determined as follows:

$$R_{1,2,3,4} = \frac{R_{1,2,3}R_4}{R_{1,2,3} + R_4} = \frac{6 \times 12}{6 + 12} = \frac{72}{18} = 4 \text{ ohms}$$

This equivalent resistance is in series with R_5. Thus, the total resistance (R_t) of the circuit is

$$R_t = R_{1,2,3,4} + R_5 = 4 + 8 = 12 \text{ ohms}$$

By Ohm's Law, the line current (I_t) is

$$I_t = \frac{E_s}{R_t} = \frac{54}{12} = 4.5 \text{ amperes}$$

The line current flows through R_5 and therefore the voltage drop, E_5, across R_5 is

$$E_5 = I_tR_5 = 4.5 \times 8 = 36 \text{ volts}$$

According to Kirchhoff's voltage law, the sum of the voltage drops around the circuit is equal to the source voltage; accordingly, the voltage between points a and d is

$$E_{ad} = E_s - E_5 = 54 - 36 = 18 \text{ volts}$$

The current through R_4 is

$$I_4 = \frac{E_4}{R_4} = \frac{18}{12} = 1.5 \text{ amperes}$$

The resistance, $R_{1,2,3}$, of parallel resistors R_1 and R_2 in series with resistor R_3 is 6 ohms. E_{ad} is applied across 6 ohms; therefore the current, I_3, through R_3 is

$$I_3 = \frac{E_{ad}}{R_{1,2,3}} = \frac{18}{6} = 3 \text{ amperes}$$

The voltage drop, E_3, across R_3 is

$$E_3 = I_3R_3 = 3 \times 4 = 12 \text{ volts}$$

and the voltage across the parallel combination of R_1 and R_2—that is, E_{bc}—is

$$E_{bc} = I_{1,2}R_{1,2} = 3 \times 2 = 6 \text{ volts}$$

where $I_{1,2}$ is the current through the parallel combinations of R_1 and R_2. By Kirchhoff's current law, $I_{1,2}$ is equal to I_3. The current, I_1 through R_1 is

$$I_1 = \frac{E_{bc}}{R_1} = \frac{6}{3} = 2 \text{ amperes}$$

and the current, I_2, through R_2 is

$$I_2 = \frac{E_{bc}}{R_2} = \frac{6}{6} = 1 \text{ ampere}$$

The preceding computations may be checked by the application of Kirchhoff's voltage and current law to the entire circuit. Briefly, the sum of the voltage drops around the circuit is equal to the source voltage. Voltage E_5 across R_5 is 36 volts and voltage E_{ad} across R_4 is 18 volts—that is,

$$E_s = E_5 + E_{ad}$$

or

$$54 = 36 + 18 \text{ volts}$$

Likewise, the voltage drop, E_{bc}, across the parallel combination of R_1 and R_2 plus the voltage drop, E_3, across R_3 should be equal to the voltage across points a and d. E_{bc} is 6 volts and E_3 is 12 volts. Therefore,

$$E_{ad} = E_{bc} + E_3 = 6 + 12 = 18 \text{ volts}$$

Kirchhoff's current law says in effect that the sum of the branch currents is equal to the line current, I_t. The line current is 4.5 amperes, and therefore the sum of I_4 and I_3 should be 4.5 amperes, or

$$I_t = I_4 + I_3 = 1.5 + 3 = 4.5 \text{ amperes}$$

The power consumed in a circuit element is determined by one of the three power formulas. For example, in figure 5-17 the power, P_1 consumed in R_1 is

$$P_1 = I_1E_{bc} = 2 \times 6 = 12 \text{ watts}$$

the power P_2 consumed in R_2 is

$$P_2 = I_2E_{bc} = 1 \times 6 = 6 \text{ watts}$$

the power P_3 consumed in R_3 is

$$P_3 = I_3E_3 = 3 \times 12 = 36 \text{ watts}$$

the power P_4 consumed in R_4 is

$$P_4 = I_4E_4 = 1.5 \times 18 = 27 \text{ watts}$$

and the power P_5 consumed in R_5 is

$$P_5 = I_5E_5 = 4.5 \times 36 = 162 \text{ watts}$$

The total power P_t, consumed is

$$\begin{aligned} P_t &= P_1 + P_2 + P_3 + P_4 + P_5 \\ &= 12 + 6 + 36 + 27 + 162 \\ &= 243 \text{ watts} \end{aligned}$$

The total power is also equal to the total current multiplied by the source voltage, or

$$P_t = I_tE_s = 4.5 \times 54 = 243 \text{ watts}$$

EFFECTS OF SOURCE RESISTANCE

The parallel circuits discussed up to this point have been explained and solved without considering the internal resistance of the source. Every known source possesses resistance. In a battery the resistance is partially due to the opposition offered to the movement of current through the electrolyte. A schematic representation of source resistance is shown in figure 5-18.

The internal resistance of the battery is labeled (R_i) and is always shown schematically connected in series with the source. Under load conditions this internal resistance will have a voltage drop across it and must be considered as part of the external circuit. The voltage at battery terminals A and B will always be less than the generated voltage of the battery since a portion of the generated voltage will be dropped across the internal resistance of the battery.

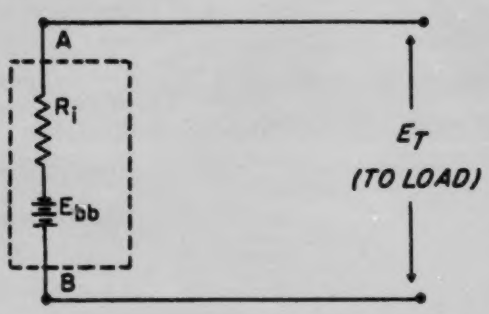

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Figure 5-18.—Battery with internal resistance.

The presence of internal resistance results in (1) a diminished voltage supplied to the components that comprise the load, (2) a decrease in total current, and (3) an increase in total resistance. The power dissipated by the circuit is also affected. The effect of internal resistance on the circuit is analyzed using the example circuit shown in figure 5-19.

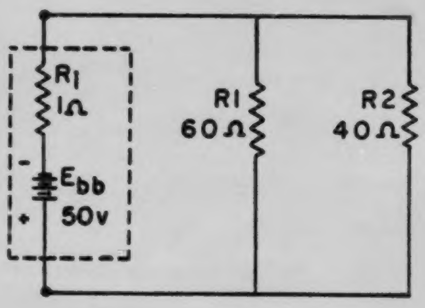

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Figure 5-19.—Effect of source resistance on a parallel circuit.

The circuit shown in figure 5-19 can no longer be classified as a parallel circuit because there is a series resistance to be considered. The circuit is solved in the following manner.

Determine R_{eq} for the parallel network:

$$R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{60 \times 40}{60 + 40} = \frac{2400}{100} = 24 \text{ ohms}$$

Reduce to an equivalent circuit (fig. 5-20).

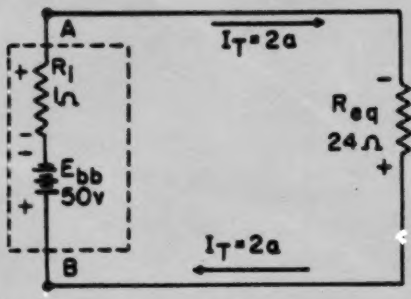

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Figure 5-20.—Equivalent circuit.

Compute the total series resistance:

$$R_t = R_i + R_{eq}$$

$$R_t = 1 + 24 = 25 \text{ ohms}$$

Compute total current:

$$I_t = \frac{E_{bb}}{R_t} = \frac{50 \text{ v}}{25} = 2 \text{ amperes}$$

Determine voltage drop across R_{eq}:

$$E_{R_{eq}} = I_t \times R_{eq}$$

$$E_{R_{eq}} = 2 \times 24$$

$$E_{R_{eq}} = 48 \text{ volts}$$

Find voltage drop across R_i:

$$E_{R_i} = I_t \times R_i$$

$$E_{R_i} = 2a \times 1 \text{ ohm}$$

$$E_{R_i} = 2 \text{ volts}$$

Determine power dissipated by load resistors:

$$P_{R_{eq}} = I_t \times E_{R_{eq}}$$

$$P_{R_{eq}} = 2a \times 48 \text{ v}$$

$$P_{R_{eq}} = 96 \text{ w}$$

Determine power dissipated by source resistance:

$$P_{R_i} = I_t \times E_{R_i}$$

$$P_{R_i} = 2a \times 2 \text{ v}$$

$$P_{R_i} = 4 \text{ w}$$

Determine total power dissipation:

$$P_t = P_{R_{eq}} + P_{R_i}$$

$$P_t = 96\text{w} + 4\text{w}$$

$$P_t = 100 \text{ w}$$

Circuit efficiency is determined by the following formula:

$$\text{Percent Eff} = \frac{P_o}{P_{in}} \times 100$$

where

Percent Eff = percent of efficiency

P_o = power supplied to load device

P_{in} = power supplied by the source

For the circuit of figure 5-20 the percent Efficiency is:

$$\text{Percent Eff} = \frac{P_o}{P_{in}} \times 100$$

$$\text{Percent Eff} = \frac{96}{96 + 4} \times 100$$

$$\text{Percent Eff} = \frac{96\text{w}}{100\text{w}} \times 100 = 96 \text{ percent}$$

From this efficiency relationship, we may conclude that the source resistance does affect the total power dissipated by the equivalent (load) resistance. The source resistance also affects the transfer of power. As stated in the preceding chapter, maximum transfer of power occurs when the circuit is 50 percent efficient, or when there is an equal amount of voltage dropped across the load and the source resistance.

OPEN AND SHORT CIRCUITS

In comparing the effects of an open in series and parallel circuits, the major difference to be noted is that an open in a parallel circuit would not necessarily disable the entire circuit; i.e., the current flow would not be reduced to zero, unless the open condition existed at some point electrically common to all other parts of the circuit.

A short circuit in a parallel network has an effect similar to a short in a series circuit. In general, the short will cause an increase in current and the possibility of component damage regardless of the type of circuit involved.

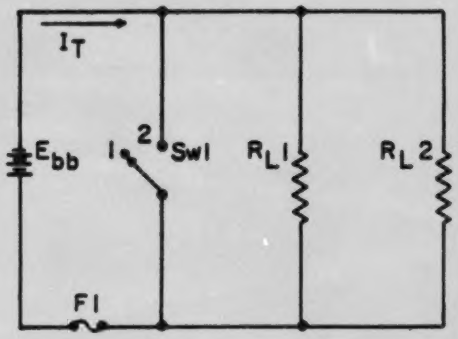
Opens and shorts, alike, if occurring in a branch circuit of a parallel network, will result in an overall change in the equivalent resistance. This can cause undesirable effects in other parts of the circuit due to the corresponding change in the total current flow.

To prevent damage to equipment due to a short circuit, a fuse or overload relay is normally placed in the circuit in series with the more sensitive components or in series with the source. The effects of a short circuit occurring in a fused network is shown in figure 5-21 and is explained as follows:

In figure 5-21, with the switch in position one (as shown), a value of current flows that does not exceed the rated current capacity of the fuse. If the switch is thrown to position two, the straight wire conductor will be in parallel with the load resistors. The equivalent resistance of the straight wire and the resistors, all connected in parallel, will be less than the resistance of the straight wire. This follows from the fact that the total resistance of a parallel circuit is always less than the smallest resistance in the branch. Since a complete path still exists to permit current flow, and the equivalent resistance is effectively zero, the current will rise rapidly until the current capacity of the fuse is reached. The fuse will then open the circuit causing the current to stop flowing. A short usually causes components to fail in a circuit which is not properly fused, or otherwise protected. The failure may take the form of a burned-out resistor, damaged source, or a fire in the circuit components and wiring.

VOLTAGE DIVIDER

In practically all electronic devices, such as radio receivers and transmitters, certain design requirements recur again and again. For instance, a typical radio receiver may require a number of different voltages at various points in its circuitry. In addition, all the various voltages must be derived from a single primary power supply. The most common method of meeting these requirements is by the use of a voltage-divider network. A typical voltage divider consists of two or more resistors connected in series across the primary power supply. The primary voltage E_s must be as high or higher than any of the individual voltages it is to supply. As the primary voltage is dropped by successive steps through the series resistors, any desired fraction of the original voltage may be "tapped off" to supply individual requirements. The values of the series resistors to be used is dictated by the voltage drops required.



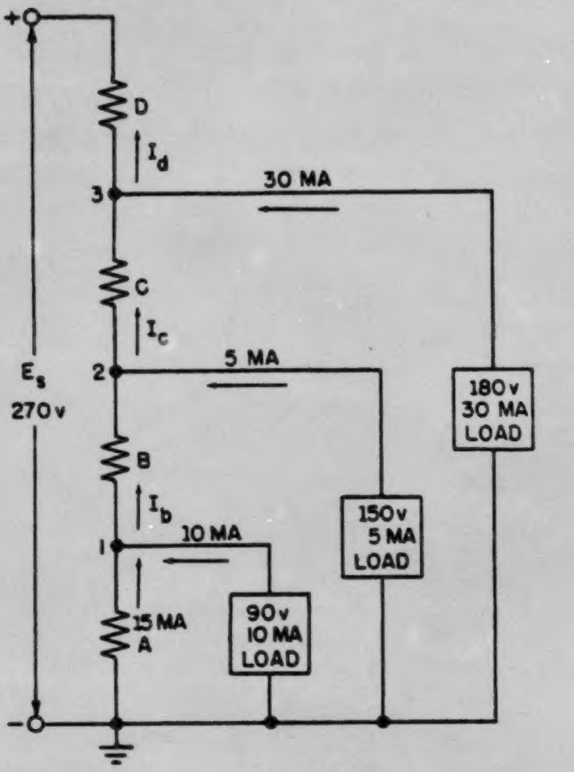
BE. 102

Figure 5-21.—Example of a circuit protected from shorts by a fuse.

If the total current flowing in the divider circuit is affected by the loads placed on it, then the voltage drops of each divider resistor will also be affected. When a voltage divider is being designed, the maximum current drawn by the loads will determine the value of the resistors that form the voltage divider. Normally, the resistance values chosen for the divider will permit a current equal to 10 percent of the total current drawn by the external loads. This current which does not flow through any of the load devices is called bleeder current.

A voltage divider circuit is shown in figure 5-22. The divider is connected across a 270-volt source and supplies three loads simultaneously—10 ma (1 milliampere is 0.001 ampere) at 90 volts, between terminal 1 and ground; 5 ma at 150 volts, between terminal 2 and ground; and 30 ma at 180 volts, between terminal 3 and ground. The current in resistor A is 15 ma. The current, voltage, resistance, and power of the 4 resistors are to be determined.

Kirchhoff's law of currents applied to terminal 1 indicates that the current in resistor B



BE.103

Figure 5-22.—Voltage divider, to determine R and P.

is equal to the sum of 15 ma from resistor A and 10 ma from the 90-volt load. Thus,

$$I_b = 15 + 10 = 25 \text{ ma}$$

Similarly,

$$I_c = 25 + 5 = 30 \text{ ma}$$

and

$$I_d = 30 + 30 = 60 \text{ ma}$$

Kirchhoff's voltage law indicates that the voltage across resistor A is 90 volts; the voltage across B is

$$E_b = 150 - 90 = 60 \text{ volts}$$

the voltage across C is

$$E_c = 180 - 150 = 30 \text{ volts}$$

and the voltage across D is

$$E_d = 270 - 180 = 90 \text{ volts}$$

Before solving for the various resistances, it should be recalled that in the formula, $R = \frac{E}{I}$, R will be in ohms if E is in volts and I is in amperes. In many electronic circuits, particularly those being considered, it is just as valid and considerably simpler to let R be in thousands of ohms (k-ohms), E in volts, and I in milliamperes. In the following formulas this convention will be followed.

Applying Ohm's law to determine the resistances—

resistance of A if $R_a = \frac{E_a}{I_a} = \frac{90}{15} = 6$ k-ohms

resistance of B if $R_b = \frac{E_b}{I_b} = \frac{60}{25} = 2.4$ k-ohms

resistance of C is $R_c = \frac{E_c}{I_c} = \frac{30}{30} = 1$ k-ohm

resistance of D is $R_d = \frac{E_d}{I_d} = \frac{90}{60} = 1.5$ k-ohms

The power absorbed by

resistor A is $P_a = E_a I_a = 90 \times 0.015 = 1.35$ watts

resistor B is $P_b = E_b I_b = 60 \times 0.025 = 1.50$ watts

resistor C is $P_c = E_c I_c = 30 \times 0.030 = 0.90$ watt

resistor D is $P_d = E_d I_d = 90 \times 0.060 = 5.40$ watts

The total power absorbed by the 4 resistors is

$$1.35 + 1.50 + 0.90 + 5.40 = 9.15 \text{ watts}$$

The power absorbed by the load connected to

terminal 1 is $P_1 = E_1 I_1 = 90 \times 0.010 = 0.90$ watt

terminal 2 is $P_2 = E_2 I_2 = 150 \times 0.005 = 0.75$ watt

terminal 3 is $P_3 = E_3 I_3 = 180 \times 0.030 = 5.4$ watts

The total power supplied to the 3 loads is

$$0.90 + 0.75 + 5.4 = 7.05 \text{ watts}$$

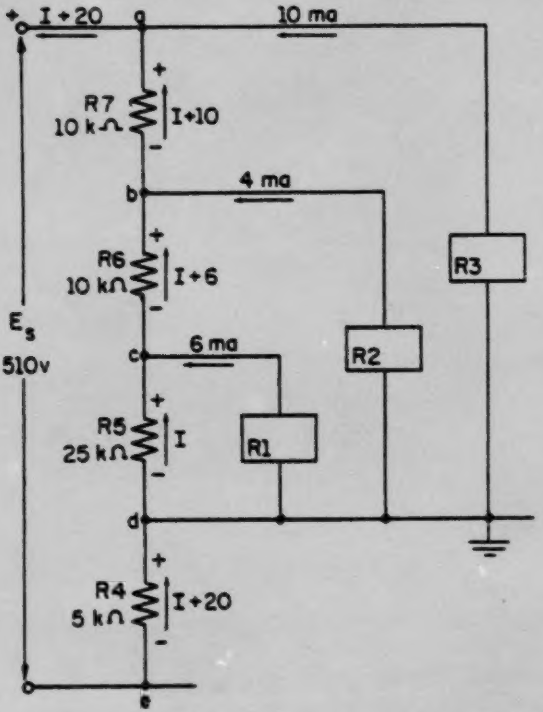
The total power supplied to the entire circuit including the voltage divider and the 3 loads is

$$9.15 + 7.05 = 16.2 \text{ watts}$$

This value is checked as

$$P_t = E \times I_t = 270 \times 0.060 = 16.2 \text{ watts}$$

In figure 5-23 the voltage divider resistances are given and the current in R_5 is to be found. The load current in R_1 is 6 ma; the current in R_2 is 4 ma; and the current in R_3 is 10 ma. The source voltage is 510 volts. Kirchhoff's current law may be applied at the junctions a, b, c, and d to determine expressions for the current in resistors R_4, R_5, R_6, and R_7. Accordingly, the current in R_4 is $I + 6 + 4 + 10$, or $I + 20$; the current in R_5 is I; the current in R_6 is $I + 6$; the current in R_7 is $I + 6 + 4$, or $I + 10$.



BE.104

Figure 5-23.—Voltage divider, to determine E and R.

The voltage across R_4 may be expressed in terms of the resistance in k-ohms and the current in milliamperes as $5(I + 20)$ volts. Similarly, the voltage across R_5 is equal to 25I; the voltage across R_6 is $10(I + 6)$ and the voltage across R_7 is $10(I + 10)$. Kirchhoff's law of voltages may be applied to the voltage divider to solve for the unknown current, I, by expressing the source voltage in terms of the given values of voltage, resistance, and current (both known and unknown values). The sum of the voltages across R_4, R_5, R_6, and R_7 is equal to the source voltage as follows:

$$E_4 + E_5 + E_6 + E_7 = E_s$$

$$5(I + 20) + 25\,I + 10(I + 6) + 10(I + 10) = 510$$

$$5\,I + 100 + 25\,I + 10\,I + 60 + 10\,I + 100 = 510$$

$$50\,I + 260 = 510$$

$$50\,I = 510 - 260$$

$$50\,I = 250$$

$$I = 5 \text{ ma}$$

The current of 5 ma through R_5 produces a voltage drop across R_5 of 5 x 25, or 125 volts. Since R_1 is in parallel with R_5, the voltage across load R_1 is 125 volts. The current through R_4 is $5 + 20$, or 25 ma and the corresponding voltage is 5 x 25, or 125 volts. Since point d is at ground potential, point c is 125 volts positive with respect to ground, whereas point e is 125 volts negative with respect to ground. The current in R_6 is $5 + 6$ or 11 ma and the voltage drop across R_6 is 11 x 10, or 110 volts. The current in R_7 is $5 + 10$, or 15 ma and the voltage drop is 15 x 10 or 150 volts. The total voltage is the sum of the voltages across the divider. Thus,

$$125 + 125 + 110 + 150 = 510$$

The power absorbed by each resistor in the voltage divider may be found by multiplying the voltage across the resistor by the current in the resistor. If the current is expressed in amperes and the emf in volts, the power will be expressed in watts. Thus the power in R_4 is

$$P_4 = E_4 I_4 = 125 \times 0.025 = 3.125 \text{ watts}$$

Similarly the power in R_5 is $125 \times 0.005 = 0.625$ watt; the power in R_6 is $110 \times 0.011 = 1.21$ watts; and in R_7 is $150 \times 0.015 = 2.25$ watts. The total power in the divider is

$$3.125 + 0.625 + 1.21 + 2.25 = 7.21 \text{ watts}$$

The voltage across load R_1 is the voltage across R_5, or 125 volts. The power in R_1 is

$$P_1 = E_1 I_1 = 125 \times 0.006 = 0.750 \text{ watts}$$

The voltage across load R_2 is equal to the sum of the voltages across R_5 and R_6. Thus,

$$E_2 = E_5 + E_6 = 125 + 110 = 235 \text{ volts}$$

The power in load R_2 is

$$P_2 = E_2 I_2 = 235 \times 0.004 = 0.940 \text{ watt}$$

The voltage across load R_3 is equal to the sum of the voltages across R_5, R_6, and R_7. Thus,

$$E_3 = E_5 + E_6 + E_7 = 125 + 110 + 150 = 385 \text{ volts}$$

The power in load R_3 is

$$P_3 = E_3 I_3 = 385 \times 0.010 = 3.85 \text{ watts}$$

The total power in the three loads is

$$0.75 + 0.94 + 3.85 = 5.54 \text{ watts}$$

and the total power supplied by the source is equal to the sum of the power absorbed by the voltage divider and the three loads, or

$$7.21 + 5.54 = 12.75 \text{ watts}$$

The total power may be checked by

$$P_t = E_t I_t = 510 \times 0.025 = 12.75 \text{ watts}$$

The resistances of load resistors R_1, R_2, and R_3 are determined by means of Ohm's law as follows:

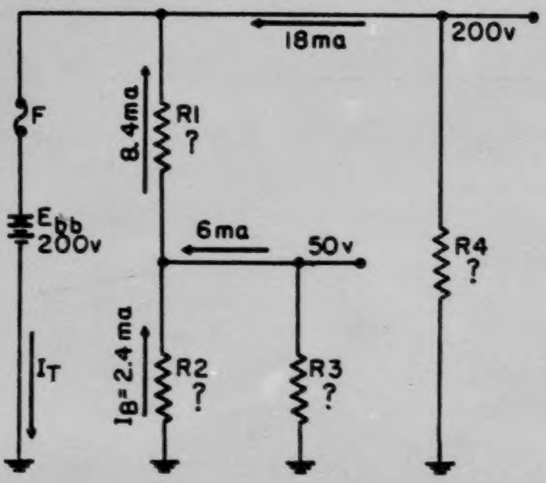
$$R_1 = \frac{E_1}{I_1} = \frac{125}{6} = 20.83 \text{ k-ohms}$$

$$R_2 = \frac{E_2}{I_2} = \frac{235}{4} = 58.75 \text{ k-ohms}$$

and

$$R_3 = \frac{E_3}{I_3} = \frac{385}{10} = 38.5 \text{ k-ohms}$$

The variation of voltages and currents found in the previous examples are undesirable in a voltage divider. It must be designed to provide voltages that are as stable as possible. A voltage divider consisting of two resistors will be designed using the circuit configuration shown in figure 5-24. The supply voltage is 200 volts. It is desired to furnish voltages of 50 and 200 volts to two loads drawing 6 and 18 milliamperes respectively. Assume bleeder current to be 10 percent of the required load current.



BE.105

Figure 5-24.—Example circuit for proposed voltage divider.

Total load current is specified as 24 milliamperes. The bleeder current, therefore, should be

$$I_b = 10 \text{ percent } I_L$$

$$I_b = 10 \text{ percent} \times 24 \text{ ma}$$

$$I_b = 2.4 \text{ ma}$$

The bleeder current and the current through resistor R_3 combine and both currents flow through R_1. This current value may be computed

$$I_{R1} = I_b + I_{R3}$$

$$I_{R1} = 2.4 \text{ ma} + 6 \text{ ma}$$

$$I_{R1} = 8.4 \text{ ma}$$

The total current may also be determined

$$I_t = 8.4 \text{ ma} + 18 \text{ ma}$$

$$I_t = 26.4 \text{ ma}$$

The resistance values of R_3 and R_4 must be as follows:

$$R_3 = \frac{E_{R3}}{I_{R3}} = \frac{50}{6 \times 10^{-3}} = 8.33 \text{ k-ohms}$$

$$R_4 = \frac{E_{R4}}{I_{R4}} = \frac{200}{18 \times 10^{-3}} = 11.1 \text{ k-ohms}$$

Computing for R_1 and R_2

$$R_1 = \frac{E_{R1}}{I_{R1}} = \frac{150}{8.4 \times 10^{-3}} = 17.85 \text{ k-ohms}$$

$$R_2 = \frac{E_{R2}}{I_{R2}} = \frac{50}{2.4 \times 10^{-3}} = 20.82 \text{ k-ohms}$$

TYPICAL PROBLEMS IN SERIES-PARALLEL CIRCUITS

As seen by the preceding calculations, problems involving the determination of resistance, voltage, current, and power in a series-parallel circuit are relatively simple. The procedure is the same as for series and parallel circuits—(1) draw the circuit diagram, (2) state the values given and the values to be found, (3) state the applicable equations, and (4) substitute the given values and solve for the unknown. For an example refer to figure 5-25.

Problems:

1. Find the resistance of branch (a).
2. Find the resistance of branch (b).
3. Find the total circuit resistance.
4. Find the total circuit current.
5. Find the voltages E_{R1}, E_a, and E_b.
6. Find the current for branch (a) and (b).
7. Find the voltages E_{R2} and E_{R5}.
8. Find the currents I_1, I_2, I_3, and I_4.
9. Find the voltages E_{R3}, E_{R6}, and E_{R7}.
10. Find the power for R_8, branches (a) and (b), and R_1.
11. Find the total circuit power.

Solutions:

1. The resistance of branch (a) R_a is

$$R_a = \frac{R_3 \times R_4}{R_3 + R_4} + R_5$$

$$R_a = \frac{100 \times 100}{100 + 100} + 50$$

$$R_a = 50 + 50 = 100 \text{ ohms}$$

2. The resistance of branch (b) R_b is

$$R_b = R_2 + \frac{(R_7 + R_8)\, R6}{R_6 + R_7 + R_8}$$

$$R_b = 20 + \frac{(80 + 80)\ 160}{80 + 80 + 160}$$

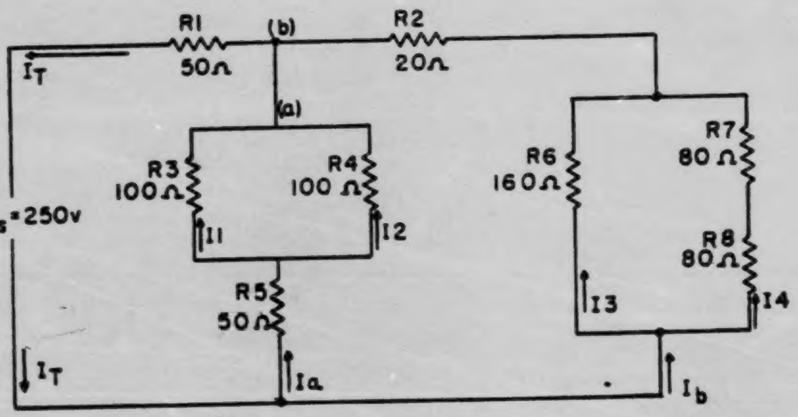
$$R_b = 20 + 80 = 100 \text{ ohms}$$

3. The total circuit resistance R_T is

$$R_T = \frac{R_a \times R_b}{R_a + R_b} + R_1$$

$$R_T = \frac{100 \times 100}{100 + 100} + 50$$

$$R_T = 50 + 50 = 100 \text{ ohms}$$



BE.106

Figure 5-25.—Typical series-parallel circuit.

4. The total circuit current is $= I_T = \frac{E}{R_T}$

$$I_T = \frac{E}{R_T} = \frac{250}{100} = 2.5 \text{ amperes}$$

5. The voltage drop of R_1 is

$$E_{R1} = I_1 R_1 = 2.5 \times 50 = 125 \text{ volts}$$

The voltage for (a) is

$$E_a = E_S - E_{R1} = 250 - 125 = 125 \text{ volts}$$

The voltage for (b) is

$$E_b = E_S - E_{R1} = 250 - 125 = 125 \text{ volts}$$

6. The current for branch (a) is

$$I_a = \frac{E_a}{R_a} = \frac{125}{100} = 1.25 \text{ amperes}$$

The current for branch (b) is

$$I_b = \frac{E_b}{R_b} = \frac{125}{100} = 1.25 \text{ amperes}$$

7. The voltage drop across R_2 is

$$E_{R2} = I_b R_2 = 1.25 \times 20 = 25 \text{ volts}$$

The voltage drop across R_5 is

$$E_{R5} = I_a R_5 = 1.25 \times 50 = 62.5 \text{ volts}$$

8. The current I_1 is

$$I_1 = \frac{E_{R3}}{R_3} = \frac{62.5}{100} = 0.625 \text{ ampere}$$

The current I_2 is

$$I_2 = I_a - I_1 = 1.25 - 0.625 = 0.625 \text{ ampere}$$

The current I_3 is

$$I_3 = \frac{E_{R6}}{R_6} = \frac{100}{160} = 0.625 \text{ ampere}$$

The current for I_4 is

$$I_4 = I_b - I_3 = 1.25 - 0.625 = 0.625 \text{ ampere}$$

9. The voltage drop across R_3 is

$$E_{R3} = I_1 R_3 = 0.625 \times 100 = 62.5 \text{ volts}$$

The voltage drop across R_6 is

$$E_{R6} = I_3 R_6 = 0.625 \times 160 = 100 \text{ volts}$$

The voltage drop across R_8 is

$$E_{R8} = I_4 R_8 = 0.625 \times 80 = 50 \text{ volts}$$

10. The power consumed by R_8 is

$$P_{R8} = I_4 E_{R8} = 0.625 \times 50 = 31.25 \text{ watts}$$

The power consumed by branch (a) is

$$P_a = I_a E_a = 1.25 \times 125 = 156.25 \text{ watts}$$

The power consumed by branch (b) is

$$P_b = I_b E_b = 1.25 \times 125 = 156.25 \text{ watts}$$

The power consumed by R_1 is

$$P_{R1} = I_{R1} E_{R1} = 2.5 \times 125 = 312.5 \text{ watts}$$

11. The total power consumed by the circuit is

$$P_T = P_{R1} + P_a + P_b = 312.5 + 156.25 + 156.25$$
$$= 625 \text{ watts}$$

or

$$P_T = E I_T = 250 \times 2.5 = 625 \text{ watts}$$

CHAPTER 8

ELECTROMAGNETISM AND MAGNETIC CIRCUITS

The fundamental theories concerning simple magnets and magnetism were discussed in chapter 2 of this manual. Those discussions dealt mainly with forms of magnetism that were not related directly to electricity—permanent magnets for instance. Only brief mention was made of those forms of magnetism having direct relation to electricity (such as "producing electricity with magnetism"). This chapter resumes the study of magnetism where chapter 2 left off. Therefore, it may be necessary for you to review parts of chapter 2 from time to time. This chapter begins the more advanced study of magnetism as it is affected by electric current flow, and the closely related study of electricity as it is affected by magnetism. This general subject area is most often referred to as electromagnetism.

Magnetism and basic electricity are so closely related that one cannot be studied at length without involving the other. This close fundamental relationship will be continually borne out in other chapters of this manual, such as in the study of generators, transformers, and motors. The technician, to be proficient in electricity, must become familiar with such general relationships that exist between magnetism and electricity as follows:

1. Electric current flow will always produce some form of magnetism.
2. Magnetism is by far the most commonly used means for producing or using electricity.
3. The peculiar behavior of electricity under certain conditions is caused by magnetic influences.

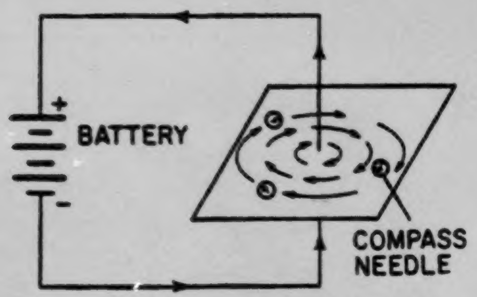
MAGNETIC FIELD AROUND A CURRENT-CARRYING CONDUCTOR

In 1819 Hans Christian Oersted, a Danish physicist, found that a definite relation exists between magnetism and electricity. He discovered that an electric current is accompanied by certain magnetic effects and that these effects obey definite laws. If a compass is place in the vicinity of a current-carrying conductor, the needle alines itself at right angles to the conductor, thus indicating the presence of a magnetic force. The presence of this force can be demonstrated by passing an electric current through a vertical conductor which passes through a horizontal piece of cardboard, as illustrated in figure 8-1. The magnitude and direction of the force are determined by setting a compass at various points on the cardboard and noting the deflection.

The direction of the force is assumed to be the direction the north pole of the compass points. These deflections show that a magnetic field exists in circular form around the conductor. When the current flows upward, the field direction is clockwise, as viewed from the top, but if the polarity of the supply is reversed so that the current flows downward, the direction of the field is counterclockwise.

The relation between the direction of the magnetic lines of force around a conductor and the direction of current flow along the conductor may be determined by means of the left-hand rule for a conductor. If the conductor is grasped in the left hand with the thumb extended in the direction of electron flow (- to +), the fingers will point in the direction of the magnetic lines of force. This is the same direction in which the north pole of a compass would point if the compass was placed in the magnetic field.

Arrows generally are used in electric diagrams to denote the direction of current flow along the length of wire. Where cross sections of wire are shown, a special view of the arrow is used. A cross-sectional view of a conductor

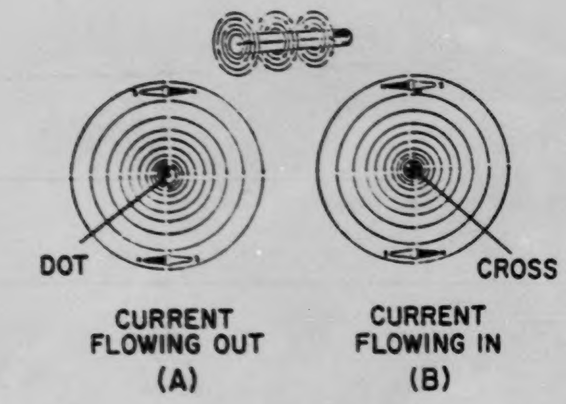


BE. 157

Figure 8-1.—Magnetic field around a current-carrying conductor.

that is carrying current toward the observer is illustrated in figure 8-2 (A). The direction of current is indicated by a dot, which represents the head of the arrow. A conductor that is carrying current away from the observer is illustrated in figure 8-2 (B). The direction of current is indicated by a cross, which represents the tail of the arrow.

When two parallel conductors carry current in the same direction, the magnetic fields tend to encircle both conductors, drawing them together with a force of attraction, as shown in figure 8-3 (A). Two parallel conductors carrying currents in opposite directions are shown in figure 8-3 (B). The field around one conductor is opposite in direction to the field around the other conductor. The resulting lines of force are crowded together in the space between the wires, and tend to push the wires apart. Therefore, two parallel adjacent conductors carrying currents in the same direction attract each other and two parallel conductors carrying currents in opposite directions repel each other.



CURRENT FLOWING OUT
(A)

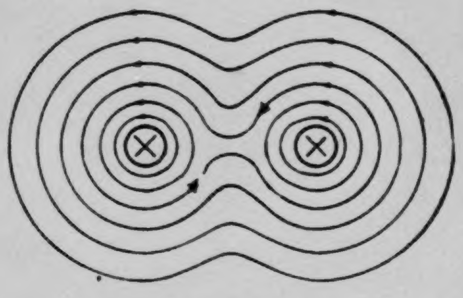
CURRENT FLOWING IN
(B)

BE. 158

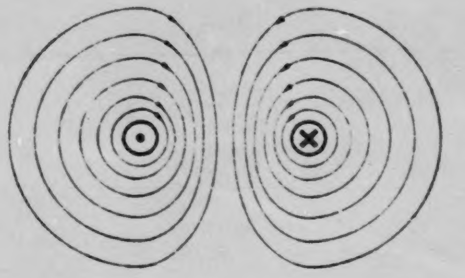
Figure 8-2.—Magnetic field around a current-carrying conductor, detailed view.

MAGNETIC FIELD OF A COIL

The magnetic field around a current-carrying wire exists at all points along its length. The field consists of concentric circles in a plane perpendicular to the wire. (See fig. 8-1.) When



CURRENTS FLOWING IN THE SAME DIRECTION
(A)



CURRENTS FLOWING IN OPPOSITE DIRECTIONS
(B)

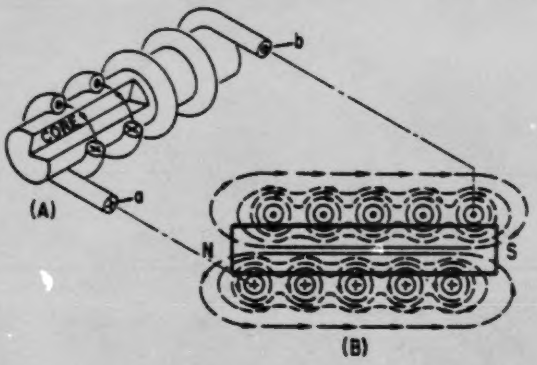
BE. 159

Figure 8-3.—Magnetic field around two parallel conductors.

this straight wire is wound around a core, as shown in figure 8-4 (A), it becomes a coil and the magnetic field assumes a different shape. Part (A) is a partial cutaway view which shows the construction of a simple coil. Part (B) is a complete cross-sectional view of the same coil. The two ends of the coil are identified as a and b. When current is passed through the coiled conductor, as indicated, the magnetic field of each turn of wire links with the fields of adjacent turns, as explained in connection with figure 8-3 (A). The combined influence of all the turns produces a two-pole field similar to that of a simple bar magnet. One end of the coil will be a north pole and the other end will be a south pole.

POLARITY OF AN ELECTROMAGNETIC COIL

In figure 8-2, it was shown that the direction of the magnetic field around a straight conductor depends on the direction of current flow through that conductor. Thus, a reversal of current flow through a conductor causes a reversal in the direction of the magnetic field that is produced. It follows that a reversal of the current flow through a coil also causes a reversal of its two-pole field. This is true because that field is the product of the linkage between the individual turns of wire on the coil. Therefore, if the field of each turn is reversed, it follows that the total field (coil's field) is also reversed.



BE. 160

Figure 8-4.—Magnetic field produced by a current-carrying coil.

When the direction of electron flow through a coil is known, its polarity may be determined by use of the left-hand rule for coils. This rule is illustrated in figure 8-5, and is stated as follows: Grasping the coil in the left hand, with the fingers "wrapped around" in the direction of electron flow, the thumb will point toward the north pole.

STRENGTH OF AN ELECTROMAGNETIC FIELD

The strength, or intensity, of a coil's field depends on a number of factors. The major factors are listed below. All of these factors are discussed under headings that follow.

1. The number of turns of conductor.
2. The amount of current flow through the coil.
3. The ratio of the coil's length to its width.
4. The type of material in the core.

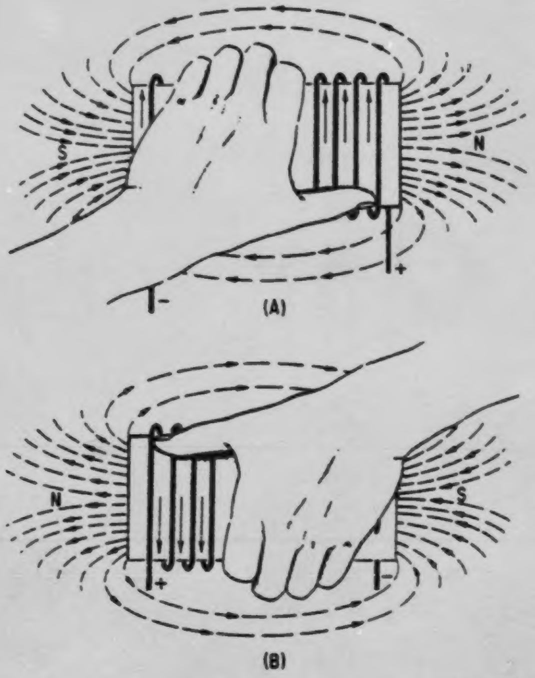


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Figure 8-5.—Left-hand rule for coil polarity.

MAGNETIC CIRCUITS

Many electrical devices depend upon magnetism in one or more forms for their operation. To have these devices function efficiently, engineers work out intricate designs for the required magnetic conditions. The magnets designed to do a particular job must have the required strength, and must be provided with paths, or circuits, of suitable shapes and materials.

A magnetic circuit is defined as the path (or paths) taken by the magnetic lines of force leaving a north pole, passing through the entire circuit and returning to the south pole. A magnetic circuit may be a series or parallel circuit or any combination.

OHM'S LAW EQUIVALENT FOR MAGNETIC CIRCUITS

The law of current flow in the electric circuit is similar to the law for the establishing of flux in the magnetic circuit.

Ohm's law for electric circuits states that the current is directly proportional to the applied voltage and inversely proportional to the resistance offered by the circuit. Expressed mathematically,

$$I = \frac{E}{R}$$

Rowland's law for magnetic circuits states, in effect, that the number of lines of magnetic flux in maxwells (Φ) is directly proportional to the magnetomotive force in gilberts (F) and inversely proportional to the reluctance ($\mathcal{R}$) offered by the circuit. The unit of reluctance sometimes used is the REL, $\mathcal{R}$. Expressed mathematically.

$$\Phi = \frac{F}{\mathcal{R}}$$

The similarity of Ohm's law and Rowland's law is apparent. However, the units used in the expression for Rowland's law need to be explained.

The magnetic flux, Φ, (phi) is similar to current in the Ohm's law formula, and comprises the total number of lines of force existing in the magnetic circuit. The maxwell is the unit of flux—that is, 1 line of force is equal to 1 maxwell. However, the maxwell is often referred to as simply a line of force, line of induction, or line.

The magnetomotive force, F, or mmf, comparable to electromotive force in the Ohm's law formula, is the force that produces the flux in the magnetic circuit. The practical unit of magnetomotive force is the ampere-turn. Another unit of magnetomotive force sometimes used is the gilbert, designated by the capital letter, F. The gilbert is the magnetomotive force required to establish 1 maxwell in a magnetic circuit having 1 unit of reluctance (1 rel). The magnetomotive force in gilberts is expressed in terms of ampere-turns as

$$F = 1.257\ IN$$

where F is in gilberts, I is in amperes, and N is the number of complete turns of wire encircling the circuit.

The unit of intensity of magnetizing force per unit of length is designated as H, and is sometimes expressed as gilberts per centimeter of length. Expressed mathematically,

$$H = \frac{1.257\ IN}{l}$$

where l is the length in centimeters.

The reluctance, $\mathcal{R}$, similar to resistance in the Ohm's law formula, is the opposition offered by the magnetic circuit to the passage of magnetic flux. The unit of reluctance, symbol $\mathcal{R}$ pronounced REL, is the reluctance of 1 centimeter-cube of air. The reluctance of a magnetic substance varies directly as the length of the flux path and inversely as the cross-sectional area and the permeability, μ, of the substance. Expressed mathematically,

$$\mathcal{R} = \frac{l}{\mu A}$$

where l is the length in centimeters, and A is the cross-sectional area in square centimeters.

Permeability, designated by the Greek letter mu, μ, is treated under a separate heading. However, it is defined here to permit a fuller interpretation of Rowland's law and also a practical application of this law. Permeability is a measure of the relative ability of a substance to conduct magnetic lines of force as compared with air. The permeability of air is taken as 1. Permeability is indicated as the ratio of the flux density in lines per square centimeter (gauss, B) to the intensity of the magnetizing force in gilberts per centimeter of length, indicated by H. Expressed mathematically,

$$\mu = \frac{B}{H}$$

Another term used in magnetic circuits is permeance. Permeance, indicated by the symbol P, is the reciprocal of reluctance—that is,

$$P = \frac{1}{\mathcal{R}}$$

Values of B, H, and μ for common magnetic substances are given in table 8-1.

Table 8-1.—B, H, and μ for common magnetic material.

B	Sheet steel		Cast steel		Wrought iron		Cast iron	
	H	μ	H	μ	H	μ	H	μ
3,000	1.3	2,310	2.8	1,070	2.0	1,500	5.0	600
4,000	1.6	2,500	3.4	1,177	2.5	1,600	8.5	471
5,000	1.9	2,630	3.9	1,281	3.0	1,666	14.5	347
6,000	2.3	2,605	4.5	1,332	3.5	1,716	24.0	250
7,000	2.6	2,700	5.1	1,371	4.0	1,750	38.5	182
8,000	3.0	2,666	5.8	1,380	4.5	1,778	60.0	133
9,000	3.5	2,570	6.5	1,382	5.0	1,800	89.0	101
10,000	3.9	2,560	7.5	1,332	5.6	1,782	124.0	80.6
11,000	4.4	2,500	9.0	1,222	6.5	1,692	166.0	66.4
12,000	5.0	2,400	11.5	1,042	7.9	1,520	222.0	54.1
13,000	6.0	2,166	16.0	813	10.0	1,300	290.0	44.8
14,000	9.0	1,558	21.5	651	15.0	934	369.0	38.0
15,000	15.5	970	32.0	469	25.0	600	....	...
16,000	27.0	594	49.0	327	49.0	327	....	...
17,000	52.5	324	74.0	230	93.0	183	....	...
18,000	92.0	196	115.0	156	152.0	118	....	...
19,000	149.0	127	175.0	108	229.0	83	....	...
20,000	232.0	86	285.0	70	....	....	....	...

*B = flux density in lines per square centimeter; H = gilberts per centimeter of length; μ = permeability; $\mu = \frac{B}{H}$.

Permeance is like conductance in electric circuits, and is defined as the property of a magnetic circuit that permits lines of magnetic flux to pass through the circuit.

A comparison of the units, symbols, and equations used in applying Ohm's law to electric circuits and Rowland's law to magnetic circuits is given in table 8-2.

As a practical application of Rowland's law, let it be required to find the ampere-turns (IN) necessary to produce 20,000 lines of flux in a cast steel ring having a cross-sectional area of 4 square centimeters and an average length of 20 centimeters, as shown in figure 8-6.

Flux density B is expressed as

$$B = \frac{\Phi}{A} = \frac{20,000}{4} = 5,000 \text{ lines/cm.}^2$$

and from table 8-1 the corresponding value of H for cast steel is 3.9. The formula for H has previously been given as

$$H = \frac{1.257\ IN}{l}$$

from which

$$IN = \frac{Hl}{1.257}$$

Substituting 3.9 for H and 20 for l in the preceding equation,

$$IN = \frac{3.9 \times 20}{1.257} = 62 \text{ ampere-turns}$$

Table 8-2.—Comparison of electric and magnetic circuits.

	Electric circuit	Magnetic circuit
Force.	Volt, E, or e.m.f.	Gilberts, F, or m.m.f.
Flow	Ampere, I	Flux, Φ, in maxwells
Opposition.	Ohms, R	Reluctance, $\mathfrak{R}$, or rels
Law.	Ohm's law, $I = \frac{E}{R}$	Rowland's law, $\Phi = \frac{F}{\mathfrak{R}}$
Intensity of force .	Volts per cm. of length	$H = \frac{1.257IN}{l}$, gilberts per centimeter of length.
Density.	Current density—for example, amperes per cm.^{2}.	Flux density, *B*.—for example, lines per cm.^{2}, or gausses.

PROPERTIES OF MAGNETIC MATERIALS

PERMEABILITY

When an annealed sheet steel core is used in an electromagnet it produces a stronger magnet than if a cast iron core is used. This is true because annealed sheet steel is more readily acted upon by the magnetizing force of the coil than is hard cast iron. Therefore, soft sheet steel is said to have greater permeability because the magnetic lines are established more easily in it than in cast iron. The ratio of the flux produced by a coil when the core is iron (or some other substance) to the flux produced when the core is air is called the permeability of the iron (or whatever substance is used), the current in the coil being the same in each case.

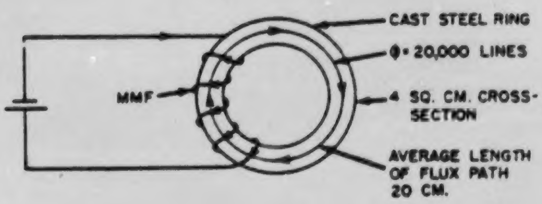

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Figure 8-6.—Determining ampere-turns in a magnetic circuit.

The permeability of a substance is thus a measure of the relative ability to conduct magnetic lines of force, or its magnetic conductivity. The permeability of air is 1. The permeability of nonmagnetic materials, such as wood, aluminum, copper, and brass is essentially unity, or the same as for air.

Magnetization curves for the four magnetic materials listed in table 8-1 are given in figure 8-7.

The permeability of magnetic materials varies with the degree of magnetization, being smaller for high values of flux density, as is indicated in table 8-1 and figure 8-8.

HYSTERESIS

The simplest method of illustrating the property of hysteresis is by graphical means such as the hysteresis loop shown in figure 8-9.

In this figure the magnetizing force is indicated in gilberts per centimeter of length along the plus and minus H axis, and the flux density is indicated in gausses along the plus and minus B axis. The intensity of the magnetizing force, H, applied by means of a current-carrying coil of wire around the sample of magnetic material, is varied uniformly through one cycle of operation, starting at zero. The force, H, is increased in the positive direction (current flowing in a given direction through the coil) to 11 gilberts per centimeter. During this time the flux density, B, increases from zero to 14,000 at point A. If H is decreased to zero, the descending curve of flux density does not return to zero via its rise path. Instead, it returns to point

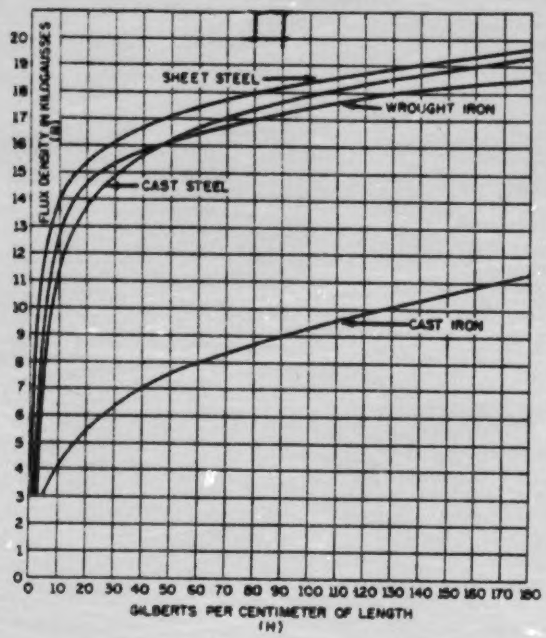

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Figure 8-7.—Magnetization curves for four magnetic materials.

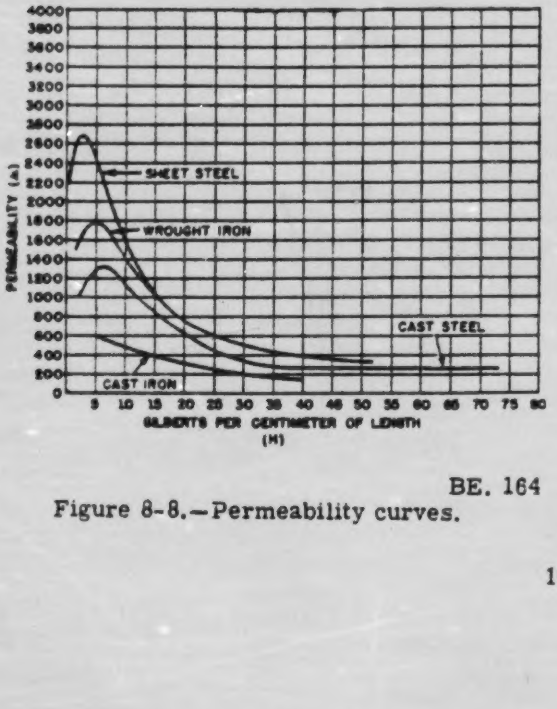

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Figure 8-8.—Permeability curves.

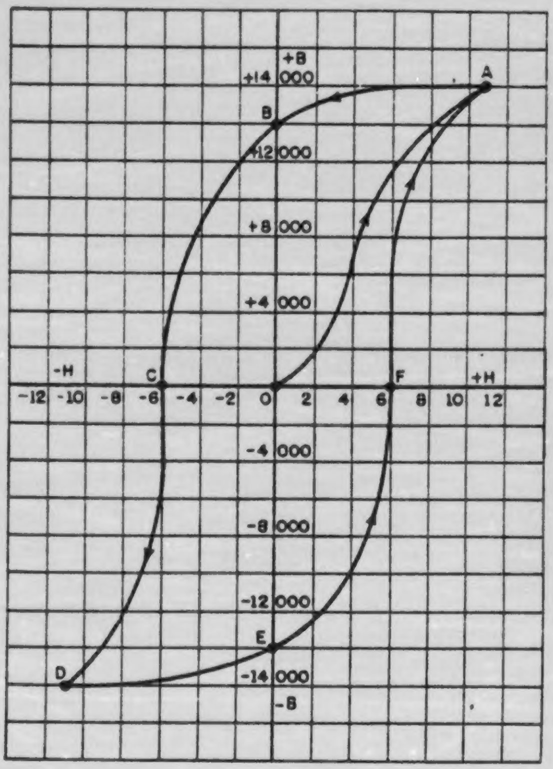

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Figure 8-9.—Hysteresis loop.

B, where the flux density is 13,000. The magnetic flux indicated by the length of line OB represents the retentivity of the magnetic substance.

Retentivity is the ability of a magnetic substance to retain its magnetism after the magnetizing force has been removed. Retentivity is most apparent in hard steel and is least apparent in soft iron.

The value of the residual, or remaining, magnetism when H has been reduced to zero, depends on the substance used and the degree of flux density attained. In this example the residual magnetism is 13,000 gausses.

If current is now sent through the coil in the opposite direction, so that the intensity of the magnetizing force becomes -H, the force will have to be increased to point C before the residual magnetism is reduced to zero. The magnetizing force, OC, necessary to reduce the residual magnetism to zero is called the coercive force. In this example the coercive force is 6 gilberts per centimeter.

If the magnetizing force is continued to -11 gilberts per centimeter, the curve descends from C to D, magnetizing the sample of magnetic material with the opposite polarity. If the magnetizing force is reduced again to zero, the flux density is reduced to point E. The magnetic flux indicated by the length of line OE represents the retentivity of the magnetic substance, as did line OB. The residual magnetism is again 13,000 gausses.

If the current through the coil is again reversed (sent through in the original direction), the magnetization curve moves to zero when the magnetising force is increased to point F.

Thus, when the magnetizing force goes through a complete cycle, the resulting magnetization likewise goes through a complete cycle.

From the foregoing analysis it is apparent that hysteresis is the property of a magnetic substance that causes the magnetization to lag behind the force that produces it. The lag of magnetization behind the force that produces it is caused by molecular friction. Energy is needed to move the molecules (or domains) through a cycle of magnetization. If the magnetization is reversed slowly, the energy loss may be negligible. However, if the magnetization is reversed rapidly, as when commercial alternating current is used, considerable energy may be disipated. If the molecular friction is great, as when hard steel is used, the losses may be very great. Another factor that determines hysteresis loss is the maximum density of the flux established in the magnetic material.

A comparison of the hysteresis loops for annealed steel and hard steel is shown in figure 8-10. The area within each loop is a measure of the hysteresis energy loss per cycle of operation. Thus, as shown in the figure, more energy is dissipated in molecular friction in hard steel than in annealed steel. It is therefore important that substances having low hysteresis loss be used for transformer cores and similar a-c applications.

ELECTROMAGNETS

An electromagnet is composed of a coil of wire wound around a core of soft iron. When direct current flows through the coil the core will become magnetized with the same polarity that the coil (solenoid) would have without the core. If the current is reversed, the polarity of both the coil and the soft-iron core is reversed.

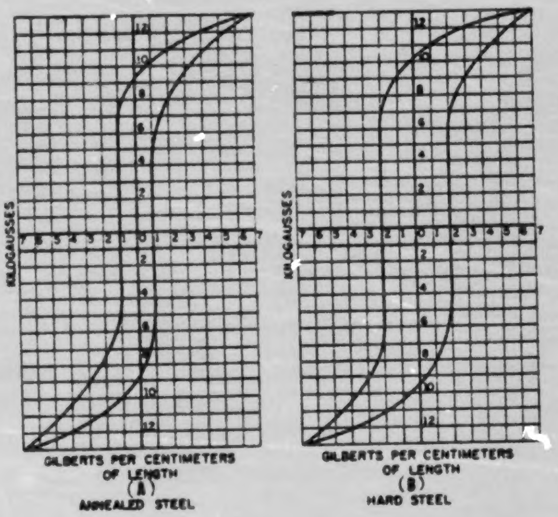

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Figure 8-10.—Comparison of hysteresis loops.

The polarity of the electromagnet is determined by the left-hand rule in the same manner that the polarity of the solenoid in figure 8-5 was determined. If the coil is grasped in the left hand in such a way that the fingers curve around the coil in the direction of electron flow (- to +), the thumb will point in the direction of the north pole.

The addition of the soft-iron core does two things for the current-carrying coil, or solenoid. First, the magnetic flux is increased because the soft-iron core is more permeable than the air core; second, the flux is more highly concentrated. The permeability of soft iron is many times that of air, and therefore the flux density is increased considerably when a soft-iron core is inserted in the coil.

The magnetic field around the turns of wire making up the coil influences the molecules in the iron bar causing, in effect, the individual molecular magnets, or domains, to line up in the direction of the field established by the coil. Essentially the same effect is produced in a soft-iron bar when it is under the influence of a permanent magnet.

The magnetomotive force resulting from the current flow around the coil does not increase the magnetism that is inherent in the iron core, it merely reorientates the "atomic" magnets that were present before the magnetizing force was applied. If substantial numbers of the tiny magnets are orientated in the same direction, the core is said to be magnetized.

When soft iron is used, most of the atomic magnets return to what amounts to a miscellaneous orientation upon removal of the magnetizing current, and the iron is said to be demagnetized, if hard steel is used, more of them will remain in alinement with the direction of the flux produced by the flow of current through the coil, and the metal is said to be a permanent magnet. Soft iron and other magnetic materials having high permeability and low retentivity are generally used in electromagnets.

It is known from experience that a piece of soft iron is attracted to either pole of a permanent magnet. A soft-iron bar is likewise attracted by a current-carrying coil, if the coil and bar are orientated as in figure 8-11. As shown in the figure, the lines of force extend through the soft iron and magnetize it. Because unlike poles attract, the iron bar is pulled toward the coil. If the bar is free to move, it will be drawn into the coil to a position near the center where the field is the strongest.

The solenoid-and-plunger type of magnet in various forms is employed extensively aboard ships and aircraft. These are used to operate the feeding mechanism of carbon-arc searchlights; to open circuit-breakers automatically when the load current becomes excessive; to close switches for motorboat starting; to fire guns; and to operate flood valves, magnetic brakes, and many other devices.

The armature-type of electromagnet also has extensive applications. In this type of magnet the coil is wound on and insulated from the iron core. The core is not movable. When current flows through the coil the iron core becomes magnetized and causes a pivoted soft-iron armature located near the electromagnet, to be attracted toward it. This type of magnet is used in door bells, relays, circuit breakers, telephone receivers, and so forth.

APPLICATIONS

Electric Bell

The electric bell is one of the most common devices employing the electromagnet. A simple electric bell is shown in figure 8-12. Its operation is explained as follows:

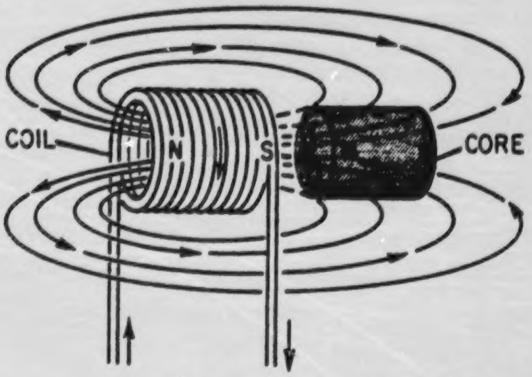

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Figure 8-11.—Solenoid with iron core.

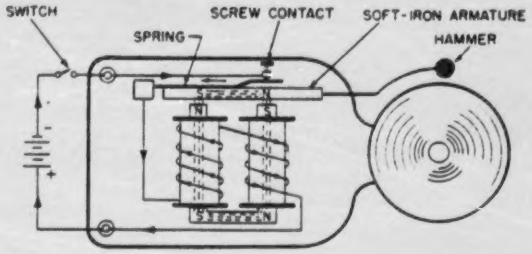

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Figure 8-12.—Electric bell.

1. When the switch is closed, current flows from the negative terminal of the battery, through the contact points, the spring, the two coils, and back to the positive terminal of the battery.
2. The cores are magnetized, and the soft-iron armature (magnetized by induction) is pulled down, thus causing the hammer to strike the bell.
3. At the instant the armature is pulled down, the contact is broken, and the electromagnet loses its magnetism. The spring pulls the armature up so that contact is reestablished, and the operation is repeated. The speed with which the hammer is moved up and down depends on the

stiffness of the spring and the mass of the moving element.

The magnetomotive forces of the two coils are in series aiding and therefore the magnetization of the core is increased over that produced by one coil alone.

Circuit Breaker

A circuit breaker, like a fuse, protects a circuit against overloading caused by excessive loads or short circuits. In this device the winding of an electromagnet is connected in series with the load circuit to be protected and with the switch contact points. The principle of operation is shown in figure 8-13. Excessive current through the magnet winding causes the switch to be tripped, and the circuit to both breaker and load is opened by a spring. When the circuit fault has been cleared, the circuit is closed again by manually resetting the circuit breaker. Circuit breakers and their applications are discussed in greater detail in chapter 14 of this manual.

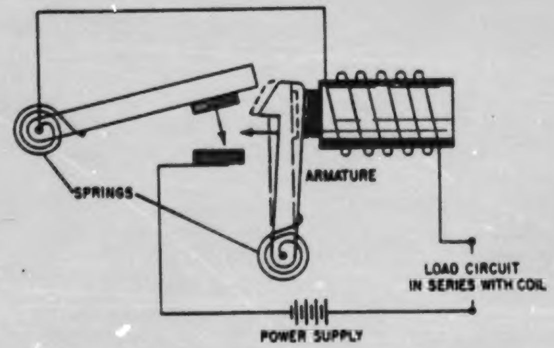

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Figure 8-13.—Magnetic circuit breaker.

Many more applications of electromagnets are discussed throughout this manual. Their applications to generators, motors, voltage regulators, reverse current relays, and servomechanisms will be covered.

CHAPTER 14

CIRCUIT PROTECTIVE AND CONTROL DEVICES

Electricity, when properly controlled, is of vital importance to the operation of equipment. When it is not properly controlled, however, it can become dangerous and destructive. It can destroy components or complete units; it can injure personnel and even cause their death.

It is of the greatest importance, then, that all precautions necessary be taken to protect the electrical circuits and units and to keep this force under proper control at all times. In this chapter some of the devices that have been developed to protect and control electrical circuits are discussed.

PROTECTIVE DEVICES

When an electrical unit is built, the greatest care is taken to insure that each separate electrical circuit is fully insulated from all others so that the current in a circuit will follow its intended individual path. Once the unit is placed into service, however, there are many things that can happen to alter the original circuitry. Some of these changes can cause serious troubles if they are not detected and corrected in time.

Perhaps the most serious trouble we can find in a circuit is a direct short. Recall that this term is used to describe a situation in which some point in the circuit, where full system voltage is present, comes in direct contact with the ground or return side of the circuit. This establishes a path for current flow that contains no resistance other than that present in the wires carrying the current, and these wires have very little resistance.

According to Ohm's Law, if the resistance in a circuit is extremely small, the current will be extremely great. When a direct short occurs, then, there will be an extremely heavy current flowing through the wires. Suppose, for instance, that the two leads from a battery to a motor came in contact with each other. Not only would the motor stop running, because of the current going through the short, but the battery would become discharged quickly (perhaps ruined), and there would also be danger of fire.

The battery cables in our example would be very large wires, capable of carrying very heavy currents. Most wires used in electrical circuits are considerably smaller, and their current-carrying capacity is quite limited. The size of the wires used in any given circuit is determined by the amount of current the wires are expected to carry under normal operating conditions. Any current flow greatly in excess of normal, such as there would be in case of a direct short, would cause a rapid generation of heat.

If the excessive current flow caused by the short is left unchecked, the heat in the wire will continue to increase until something gives way. Perhaps a portion of the wire will melt and open the circuit so that nothing is damaged other than the wires involved. The probability exists, however, that much greater damage would result. The heat in the wires could char and burn their insulation and that of other wires bundled with them, which could cause more shorts. If a fuel or oil leak is near any of the hot wires, a disastrous fire might be started.

To protect electrical systems from damage and failure caused by excessive current, several kinds of protective devices are installed in the systems. Fuses, circuit breakers, and thermal protectors are used for this purpose.

DESCRIPTION AND PURPOSE

Circuit protective devices, as the name implies, all have a common purpose: to protect the units and the wires in the circuit. Some are designed primarily to protect the wiring. These open the circuit in such a way as to stop the current flow when the current becomes greater than the wires can safely carry. Other devices are designed to protect a unit in the circuit by stopping current flow to it when the unit becomes excessively warm.

FUSES

The simplest protective device is a fuse. All fuses are rated according to the amount of current that is safely carried by the fuse element at a rated voltage. Usually, the current rating is in amperes, but some instrument fuses are rated in fractions of an ampere. When a fuse blows, it should be replaced with another of the same rated voltage and current capacity, including the same current-versus-time characteristic.

The most important fuse characteristic is its current-versus-time or "blowing" ability. Three time ranges for existence of overloads can be broadly defined as fast, medium, and delayed. FAST, may range from 5 microseconds through one-half second; MEDIUM, 1/2 to 5 seconds; DELAYED, 5 to 25 seconds.

Normally, when the circuit is overloaded, or a fault develops, the fuse element melts and opens the circuit that it is protecting. However, all fuse openings are not the result of current overload or circuit faults. Abnormal production of heat, aging of the fuse element, poor contact due to loose connections, oxides or corrosion forming within the fuse holder, and the heated condition of the surrounding atmosphere will alter the heating conditions and the time required for the element to melt.

Delayed-Action Fuses

Some equipment, such as an electric motor, requires more current during starting than for normal running. Thus, a fast-time or medium-time fuse rating that will give running protection might blow during the initial period when high starting current is required. Delayed-action fuses are used to handle these situations.

One type of delayed-action fuse has a heater element connected in parallel with the fuse element in order to get the delayed action. During normal operation, the heat developed in the fuse link is not great enough to melt the link. The melting, or opening, of the fuse link depends on the transfer of heat to the link from the heater. Therefore, more time is needed to melt the link than would be required if the link were directly heated.

Because the heater and fuse element are in parallel, the opening of the fuse element will cause the total circuit current to flow through the heater. The high current will cause the heater to burn out and completely open the circuit.

Another type of delayed-action fuse has the fuse element and heater connected in series. Current above that of the rated value for a short time will have no effect on the fuse or heater. However, prolonged overloads cause the heater section to become hot enough to melt the junction between the elements; this action opens the circuit.

Delayed-action fuses are sometimes called Time-Lag fuses; and three trade names "Slo Blo," "Fusestat," and "Fusetron" are in common use.

Plug Fuses

The plug fuse is constructed so that it can be screwed into a socket mounted on the control panel or distribution center. The fuse link is enclosed in an insulated housing of porcelain or glass. The construction is so arranged that the fuse link is visible through a window of mica or glass. Therefore, an open element may be located by visual examination. When found to be defective, the fuse is discarded and a new fuse installed in its place. The plug fuse is used primarily to protect low-voltage, low-current circuits. The operating ratings range from 0.5 to 30 amperes up to 150 volts.

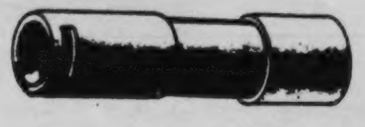
Cartridge Fuses

In operation, the cartridge fuse is exactly the same as the plug fuse. In construction, the fuse link is enclosed in a tube of insulating material with metal ferrules at each end (for contact with the fuse holder). The dimensions of cartridge fuses vary with the current and voltage ratings.

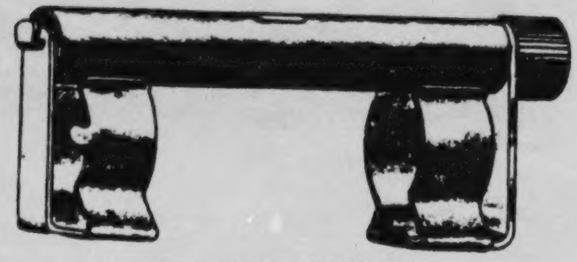
Blown-Fuse Indicators

It is not always possible to detect a blown fuse by a visual examination. Hence, fuses are often equipped with a device that will provide a visual indication so that a blown-fuse condition can be readily detected (fig. 14-1). These devices consist of the spring-loaded and the neon-lamp types of blown-fuse indicators.

In the spring-loaded type (fig. 14-1), when the link opens, it releases a spring that is held under tension. This action exposes an indicator, which makes the visual location of the blown fuse possible.



SPRING-LOADED INDICATOR



NEON-LAMP INDICATOR

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Figure 14-1.—Blown-fuse indicators.

The neon lamp type (fig. 14-1) is designed to be mounted on the fuse. When the link opens, a neon lamp glows to show a blown fuse.

When no indicator is used, it is necessary to test the fuse continuity with a megger, ohmmeter, or voltmeter. Various methods of testing will be described later in this chapter.

Most fuse panels and switchboards are of the enclosed panel type. The term "dead-front" means that all fuses and bus connections are enclosed in a metal cabinet when the cover is closed. The use of this type of construction reduces the possibility of equipment damage and danger to personnel. Modern switchboards are of the "dead-front" type.

However, the complete enclosure of the equipment makes it less accessible for test purposes. Therefore, most fuses used on "dead-front" switchboards have indicators that show when a fuse is blown. The fuse holder consists of a molded phenolic base, plug, and cap with a built-in indicator lamp (blown-fuse indicator). The lamp is usually a small neon bulb, which normally is shunted by the fuse element. When the fuse opens, the shunt is removed, causing an increase in the voltage across the neon lamp. The lamp then glows, indicating the open fuse.

TROUBLESHOOTING FUSED CIRCUITS

An electrical system may consist of a comparatively small number of circuits or, in the larger systems, the installation may be equal to that of a fair sized city.

Regardless of the size of the installation, an electrical system consists of a source of power (generators or batteries) and a means of delivering this power from the source to the various loads (lights, motors, and other electrical equipments).

From the main power supply the total electrical load is divided into several feeder circuits and each feeder circuit is further divided into several branch circuits. Each final branch circuit is fused to safely carry only its own load while each feeder is safely fused to carry the total current of its several branches. This reduces the possibility of one circuit failure interrupting the power for the entire system. The feeder distribution boxes and the branch distribution boxes contain fuses to protect the various circuits.

The distribution wiring diagram showing the connections that might be used in a lighting system is illustrated in figure 14-2. An installation might have several feeder distribution boxes, each supplying six or more branch circuits through branch distribution boxes.

Fuses F_1, F_2, and F_3 (fig. 14-2) protect the main feeder supply from heavy surges such as short circuits or overloads on the feeder cable. Fuses A-A1 and B-B1 protect branch No. 1. If trouble develops and work is to be done on branch No. 1, switch S_1 may be opened to isolate this branch. Branches 2 and 3 are protected and isolated in the same manner by their respective fuses and switches.

Branch Circuit Tests

Usually, receptacles for portable equipment and fans are on branch circuits separate from lighting branch circuits. Test procedures are the same for any branch circuit. Therefore, a description will be given of the steps necessary to (1) locate the defective circuit and (2) follow through on that circuit and find the trouble.

Assume that, for some reason, several of the lights are not working in a certain section. Because several lights are out, it will be reasonable to assume that the voltage supply has been interrupted on one of the branch circuits.

To verify this assumption, first locate the distribution box feeding the circuit that is inoperative. Then make sure that the inoperative circuit is not being supplied with voltage. Unless the circuits are identified in the distribution box,

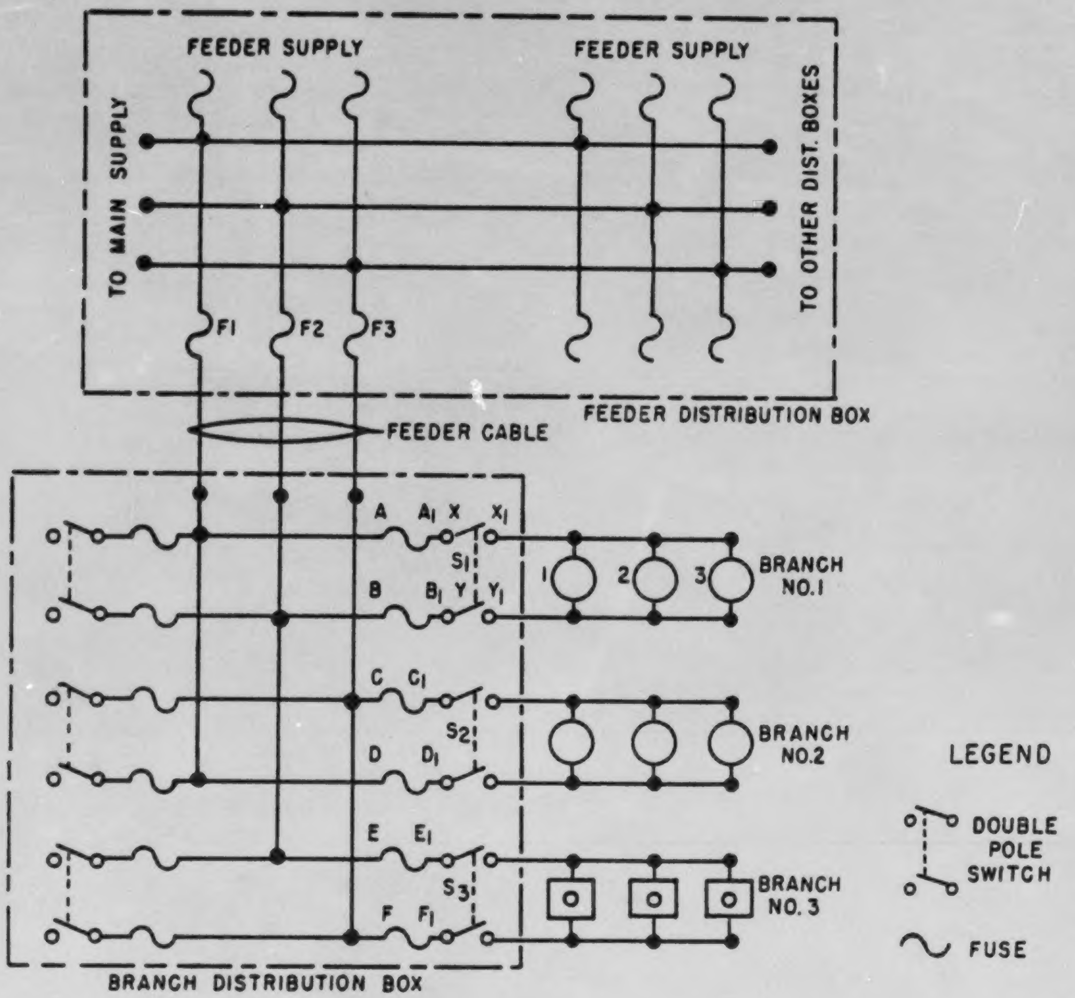
FEEDER SUPPLY
FEEDER SUPPLY
TO MAIN SUPPLY
TO OTHER DIST. BOXES
F1
F2
F3
FEEDER DISTRIBUTION BOX
FEEDER CABLE
A
A1
X
X1
S1
B
B1
Y
Y1
1
2
3
BRANCH NO.1
C
C1
S2
D
D1
BRANCH NO.2
E
E1
S3
F
F1
BRANCH NO. 3
BRANCH DISTRIBUTION BOX
LEGEND
DOUBLE POLE SWITCH
FUSE

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Figure 14-2.—Three-phase distribution wiring diagram.

the voltage at the various circuit terminations will have to be measured. For the following procedures, use the circuits shown in figure 14-2 as an example circuit.

To pin down the trouble, connect the voltage tester to the load side of each pair of fuses in the branch distribution box. No voltage between these terminals indicates a blown fuse or a failure in the supply to the distribution box. To find the defective fuse, make certain S_1 is closed, then connect the voltage tester across A-A1, and next across B-B1 (fig. 14-2). The full-phase voltage will appear across an open fuse, provided circuit continuity exists across the branch circuit. However, if there is an open circuit at some other point in the branch circuit, this test is not conclusive. If the load side of a pair of fuses does not have the full-phase voltage across its terminals, place the tester leads on the supply side of the fuses. The full-phase voltage should be present. If the full-phase voltage is not present on the supply side of the fuses, the trouble is in the supply circuit from the feeder distribution box.

Assume that you are testing at terminals A-B (fig. 14-2) and that normal voltage is present. Move the test lead from A to A1. Normal voltage between A1 and B indicates that fuse A-A1 is in good condition. To test fuse B-B1, place the tester leads on A and B, and then move the lead from B to B1. No voltage between these terminals indicates that fuse B-B1 is open. Full-phase voltage between A and B1 indicates that the fuse is good.

This method of locating blown fuses is preferred to the method in which the voltage tester leads are connected across the suspected fuse terminals, because the latter may give a false indication if there is an open circuit at any point between either fuse and the load in the branch circuit.

CIRCUIT BREAKERS

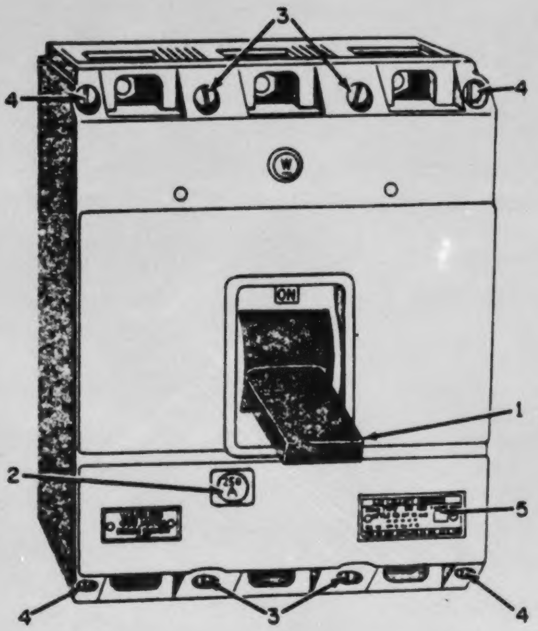
A circuit breaker is designed to break the circuit and stop the current flow when the current exceeds a predetermined value. It is commonly used in place of a fuse and may sometimes eliminate the need for a switch. A circuit breaker differs from a fuse in that is "trips" to break the circuit and it may be reset, while a fuse melts and must be replaced.

Several types of circuit breakers are commonly used. One is a magnetic type. When excessive current flows in the circuit, it makes an electromagnet strong enough to move a small armature which trips the breaker. Another type is the thermal overload switch or breaker. This consists of a bimetallic strip which, when it becomes overheated from excessive current, bends away from a catch on the switch lever and permits the switch to trip open.

Some circuit breakers must be reset by hand, while others reset themselves automatically. When the circuit breaker is reset, if the overload condition still exists, the circuit breaker will trip again to prevent damage to the circuit.

One common type of circuit breaker now being used is depicted in figure 14-3. This breaker is designed for front or rear connections as required and may be mounted so as to be removable from the front without removing the circuit breaker cover. The voltage ratings of this breaker are 500 volts a.c., 60 Hz, or 250 volts d.c. with a maximum current capacity of 250 amperes. Trip units (fig. 14-4) for this breaker are available with current ratings of 125, 150, 175, 225, and 250 amperes.

The trip unit houses the electrical tripping mechanisms, the thermal element for tripping the circuit breaker on overload conditions, and the instantaneous trip for tripping on short circuit conditions. The automatic trip devices of this circuit breaker are "trip free" of the operating handle; this means the circuit breaker cannot be held closed by the operating handle if an overload exists. When the circuit breaker has tripped due to overload or short circuit, the handle rests in a center position. To reclose after automatic tripping, the handle must be moved to the extreme OFF position which resets the latch in the trip unit; then the handle must be physically moved to the ON position. Metal locking devices are available that can be attached to the handles of circuit breakers to prevent accidental operation.



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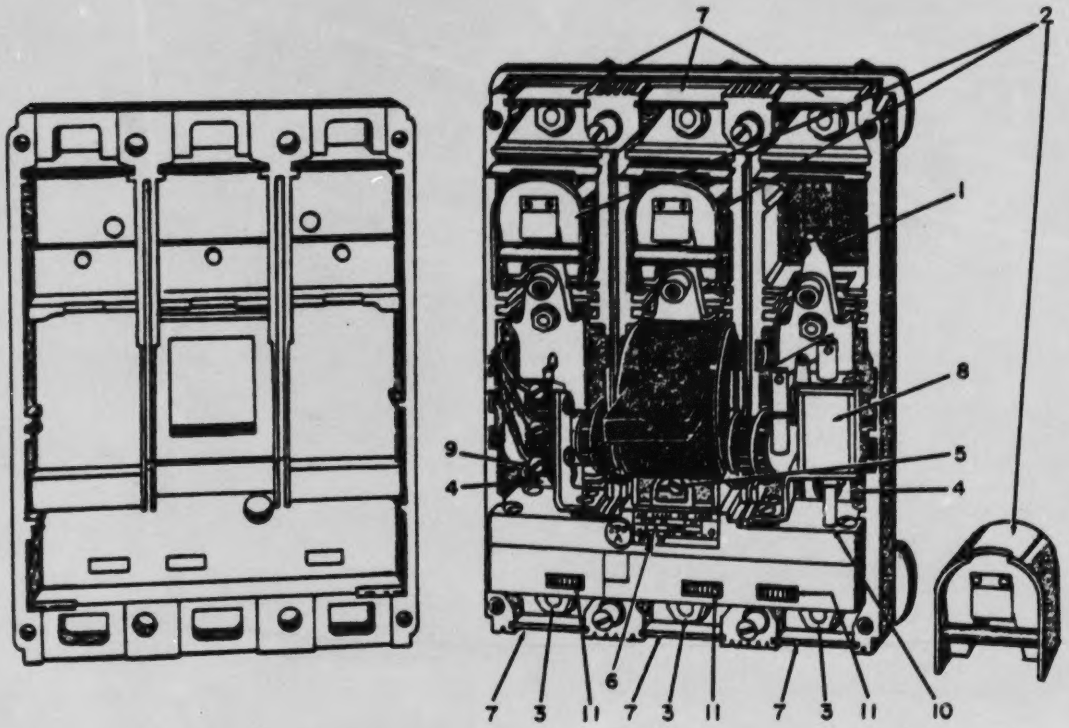
1. Operating handle shown in latched position.
2. Ampere rating maker.
3. Mounting screws.
4. Cover screws.
5. Breaker nameplate.

Figure 14-3.—Circuit breaker, front view.

THERMAL PROTECTORS

A thermal protector, or switch, is a device used to protect a motor. It is designed to open the circuit automatically whenever the temperature of the motor becomes excessively high. It has two positions, open and closed. The most



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1. Stationary contact.
2. Arc suppressors.
3. Terminal stud nuts and washers.
4. Trip unit line terminal screw-outer poles.
5. Trip unit line terminal screw-center pole.
6. Trip unit nameplate.
7. Terminal barriers.
8. Shunt trip.
9. Auxiliary switch.
10. Hole for shunt trip undervoltage release plunger.
11. Instantaneous trip adjusting wheels.

Figure 14-4.—Circuit breaker, cover and arc suppressor removed.

common use for a thermal switch is to keep a motor from overheating. If some malfunction in the motor causes it to overheat, the thermal switch will break the circuit intermittently. If the trouble is a locked rotor, the intermittent opening and closing of the circuit may release the rotor and allow the motor to resume normal operation.

The thermal switch contains a bimetallic disk, or strip, which bends and breaks the circuit when it is heated. This happens because one of the metals expands more than the other when they are subjected to the same temperature. When the strip or disk cools, the metals contract and the strip returns to its original position and closes the circuit.

OVERLOAD DEVICE

A prolonged overloaded electrical system can be damaged beyond repair by the resulting heat and flame. Therefore, it is expedient to use a device which can detect an overload before damage occurs and either warns the operator of the hazardous conditon or automatically turns off the power. Relays have been designed which are capable of accomplishing these protective functions. A few of these relays that are commonly used as overload devices are discussed in greater detail later in this manual.

CONTROL DEVICES

Control devices are those electrical accessories which govern (in some predetermined way) the power delivered to any electrical load.

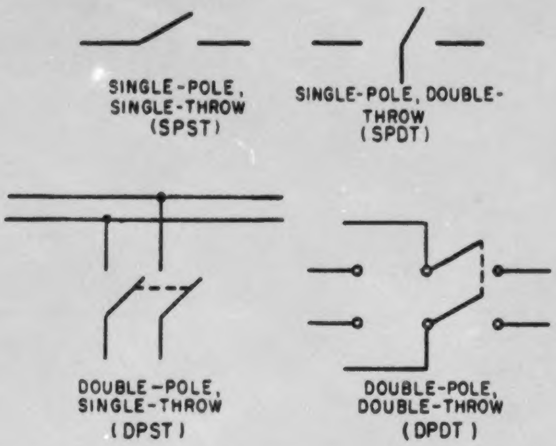
In its simplest form the control applies voltage to, or removes it from a single load. In more complex control systems, the initial switch may set into action other control devices that govern motor speeds, servomechanisms, temperatures, and numerous other equipments. In fact, all electrical systems and equipment are controlled in some manner by one or more controls. A controller is a device or group of devices which serves to govern, in some predetermined manner, the device to which it is connected.

In large electrical systems, it is necessary to have a variety of controls for operation of the equipment. These controls range from simple pushbottons to heavy duty contactors that are designed to control the operation of large motors. The pushbutton is manually operated while a contactor is electrically operated.

SWITCHES

A switch may be described as a device used in an electrical circuit for making, breaking, or changing connections under conditions for which the switch is rated. Switches are rated in amperes and volts; the rating refers to the maximum voltage and current of the circuit in which the switch is to be used. Because it is placed in series, all the circuit current will pass through the switch. Because it opens the circuit, the applied voltage will appear across the switch in the open circuit position. Switch contacts should be opened and closed quickly to minimize arcing; therefore, switches normally utilize a snap action.

Many types and classifications of switches have been developed. A common designation is by the number of poles, throws, and positions they have. The number of poles indicates the number of terminals at which current can enter the switch. The throw of a switch signifies the number of circuits each blade or contactor can complete through the switch. The number of positions indicates the number of places at which the operating device (toggle, plunger, etc.) will come to rest. Figure 14-5 presents the schematic diagrams of some often used switches.



SINGLE-POLE, SINGLE-THROW (SPST)

SINGLE-POLE, DOUBLE-THROW (SPDT)

DOUBLE-POLE, SINGLE-THROW (DPST)

DOUBLE-POLE, DOUBLE-THROW (DPDT)

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Figure 14-5.—Schematic diagrams of commonly used switches.

An example of the switch position designation is a toggle switch which comes to rest at either of two positions, opening the circuit in one position and completing it in another. This is called a two-position switch. A toggle switch which is spring loaded to the OFF position and must be held in the ON position to complete the circuit is called a momentary contact two-position switch. If the toggle switch will come to rest at any of three positions, it is called a three-position switch.

Another means of classyfying switches is the method of actuation; that is, toggle, pushbutton, sensitive, and rotary types. Further classification can be accomplished by a description of switch action such as on-off, momentary on-off, on-momentary off, etc. Momentary contact switches hold a circuit closed or open only as long as the operator deflects the actuating control.

Manually Operated Switches

One of the most common types of switches is the toggle. Toggle switches have their moving parts enclosed. A double-pole, double-throw, ON-OFF-ON toggle switch is shown in figure 14-6. These switches have many uses and are used especially for applying power to various circuits. They are often provided with a luminous tip on the lever so as to be visible in the dark.

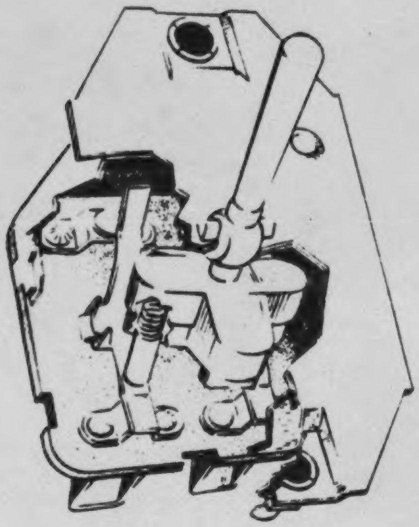
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Figure 14-6.—Toggle switch.

Pushbutton switches have one or more stationary contacts and one or more movable contacts. The movable contacts are attached to the pushbutton by an insulator. This switch is usually spring loaded and is of the momentary contact type. These switches have many uses, such as indicator light checks and circuit reset.

A rotary selector switch may perform the functions of a number of switches. As the knob of a rotary selector switch is rotated, it opens one circuit and closes another. This can be seen from an examination of figure 14-7. Some rotary switches have several layers of wafers. By adding wafers, the switch can be made to operate as a large number of switches. Ignition switches and voltmeter selector switches are typical examples of this type.

Mechanically Operated Switches

Mechanically operated switches are used in many applications. They are widely used because of their small size, light weight, and excellent dependability. The term Micro switch, although frequently used in referring to all switches of this type, is a trade name for the switches made by the Micro Switch Division of the Minneapolis Honeywell Regulator Company.

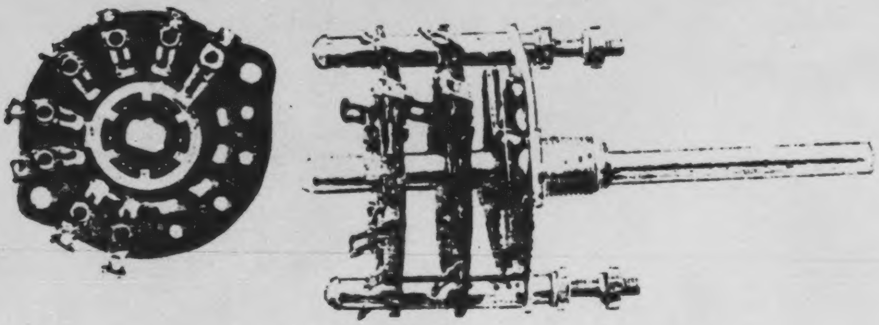
These switches will open or close a circuit with a very small movement of the tripping device (1/16 inch or less). They are usually of the pushbutton variety and depend upon one or more springs for their snap action. For example, the heart of the Micro switch is a beryllium copper spring, heat-treated for long life and unfailing action. The simplicity of the one-piece spring contributes to the long life and dependability of this switch. The basic Micro switch is shown in figure 14-8.

The versatility of the snap-action switch is shown in figure 14-9, which shows how the basic switch may be used with different type enclosures and actuators. The particular type switching unit used depends upon the function it is to perform and environmental conditions. Figure 14-9 (A) shows a lightweight aluminum enclosure which may contain one or more plastic enclosed basic switches. The plastic enclosure provides electrical insulation between the housing and the energized electrical parts, support for the terminals, and a dusttight box around the electrical contacts.

Figure 14-9 (B) shows one of the various types of switch actuators that may be used with basic switches when complete enclosures are not needed. They provide protection and mounting means. They relay the operating motion from a cam or slide to the basic switch in a way that assures long life and dependability. Figure 14-9 (C) shows a toggle type switch which uses one or more of the basic subminiature switches. These subminiature switches are smaller than the conventional Micro switch and are finding wide use in various switching arrangements.

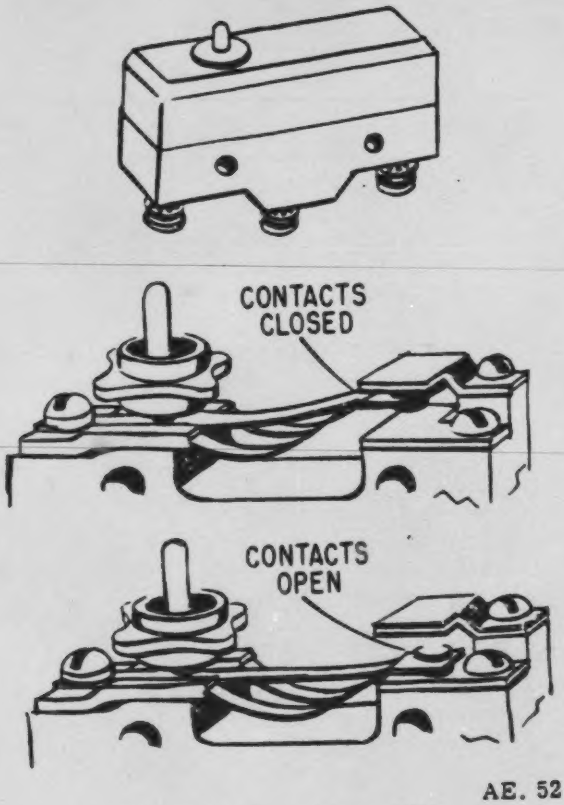
Pressure-operated switches usually have Bourdon tubes, syphons, or diaphrams against which the fluids or air operate to actuate the switch. Some uses of pressure switches are in connection with fuel, oil, and hydraulic pressure signals and electric heaters.

Thermal switches usually incorporate a bimetallic sheet that bends or snaps at a desired temperature to actuate the switch. They are used extensively as circuit breakers and also find application in controlling the igniter circuit on heater and operating signal lights at critical temperatures.



AE. 51

Figure 14-7.—Rotary selector switch.



AE. 52

Figure 14-8.—Micro switch.

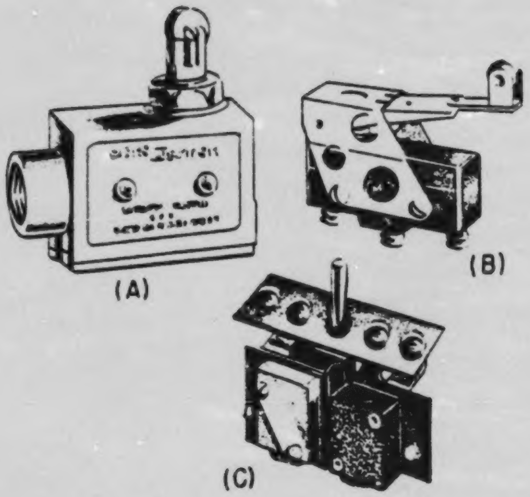
Maintenance of Switches

While the switch itself is relatively simple to check, it sometimes offers difficulty in maintenance because of its location in inaccessible places. After a visual inspection of the connections and the switch, a continuity test will indicate any malfunctions. When the switch mechanism is found to be defective, it normally is not repairable and therefore should be replaced.

When enclosed switches are used, failure to seal properly around cable openings may cause difficulty. Altitude changes permit "breathing" of moist air into enclosures with improperly sealed cable openings, and the moisture in the air may condense within the switch enclosure. The condensation can short across the switch terminals and can corrode the switch actuators in a manner that may make them inoperative. This difficulty can be corrected by careful sealing of openings or by using hermetically sealed switches. Hermetically sealed switches will also prevent dust and dirt from reaching the contacts and thereby reduce the possibility of high resistance and open circuits.

Some switches are damaged during installation, particularly those with plastic housings. Proper care in installing or replacing plastic enclosed switches will eliminate this.

Some switch assemblies are equipped with adjustments which enable them to operate at a preset time or pressure. Caution should be exercised in making these adjustments; if they are not accurate, damage can result.



AE. 53
Figure 14-9.—Snap-action switching units.

RELAYS

Relays are electrically operated switches that are classified according to their use as control relays, power relays, or sensing relays. The power relays are the workhorses of a large electrical system. As such, they control the heavy power circuits.

The function of a control relay is to take a relatively small amount of electrical power and use it either to signal or to control a large amount of power. Where multipole relays are used, several circuits may be controlled simultaneously.

The use of relays saves space and weight by permitting the use of small switches at remote control stations. These switches permit the operator to control large amounts of current at other locations and the heavy power cables need to be run only to the point of use. Only lightweight control wires are connected to the control switches. Safety is also an important factor in using relays, since high power circuits can be switched remotely without danger to the operator.

Control relays, as their name implies, are frequently used in the control of other relays, although the small control relays find many other uses. With these, small currents can control the larger currents necessary to operate electrical devices. They find frequent use in automatic relaying circuits, where a small electric signal sets off a chain reaction of successively acting relays performing various functions. Control relays can also be used in so-called "lockout" action to prevent certain functions from occurring at the improper time. Various electrical operations in the equipment which must not occur simultaneously can be "interlocked" by control relays. Another important function of control relays in equipment is for "sensing." Control relays are used for sensing undervoltage and overvoltage, reversal of current, and excessive currents.

Another possible classification of relays is open, semisealed, and sealed. Semisealed relays have protextive covers and are gasketed against entrance of salt, dust, and foreign material into the contact or mechanism area. These relays are still considered satisfactory for certain applications in current equipment. Open relays are seldom used outside of black boxes.

For other applications in today's complex equipment, however, it is necessary to go beyond the protection offered by the open type and the semisealed relays. When such relays are used, quick changes in altitude, humidity, or temperature can cause condensation of water vapor within the unit. Subsequent low temperature will then freeze the moisture on the contactor with a resultant inability to carry electric current.

Hermetically sealed relays were developed to answer the demands of complex and delicate equipment. A true hermetic seal is generally considered one that is metal to metal or glass to metal. Plastic or plastic rubber type gasketed seals are not generally considered true hermetic seals. However, both semisealed and hermetically sealed relays are used. There are applications where a gasket type sealed relay may be adequate, but the true hermetically sealed type is generally considered to be more permanent. Besides being independent of environmental changes, the hermetically sealed relay also has the advantage of being protected from improper adjustments.

In general, the basic components of a relay are as follows: the coil or solenoid, the iron core, the fixed and movable contacts, and the mounting (and if sealed, the can). A manual switch, limit switch, or other small control device starts and stops the flow of current to the magnet coil. The flow of electric current through the coil creates a strong magnetic field around and within the coil. This magnetic field moves a clapper or plunger which completes the magnetic circuit. Figure 14-10 (A) shows a basic single coil clapper type relay. The dashed lines indicate the magnetic lines of flux.

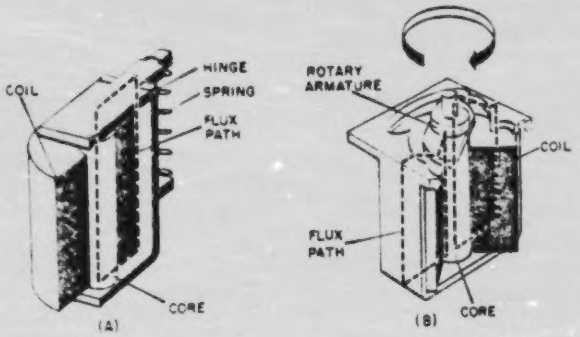


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Figure 14-10.—Basic types of relays.

The second basic type of relay is the rotary. (See fig. 14-10 (B).) Although this type of construction is not as common as the clapper type, the rotary type has greater vibration and shock resistance than the others. The disadvantage is that they are somewhat sluggish and require higher operating power for many purposes. The rotary relay operates on the principle of an electric motor, but through only a small arc. The problem of hanging contacts on such a mechanism is a difficult one, and therefore the use of these devices is limited to applications where high shock warrants the larger size and weight. When used with standard wafer switch assemblies, this type of relay provides a means for assembling a switching device of any degree of complexity.

Occasionally relays operating from an a-c supply are encountered. These a-c relays depend upon the same fundamental principles as the d-c relay; that is, magnetic fields. When a.c. is applied to an electromagnet, the current will pass through zero twice every cycle. Since the pull on the armature is proportional to the current through the electromagnet, the armature tends to open every time the current nears zero, causing chatter. To remedy this, shading coils (sometimes called shaded poles) are used.

A shading coil consists of copper band or stamping which is short-circuited and embedded around part of the electromagnet pole face. By being placed around part of the pole face, it acts as a shorted transformer secondary. The current in the main coil lags the applied voltage by approximately 90°, and the flux is in phase with the current. The voltage of the shading coil is induced voltage and lags the current in the main coil by 90°. Since the shading coil acts like a shorted secondary (resistive), the current in the shading coil is in phase with the induced voltage. Therefore, the magnetic field of the shading coil lags the magnetic field of the main coil by 90°. This means that flux will exist in the electromagnet even when the main coil current becomes zero. Thus, chattering is prevented.

The arrangements of relay contacts are found in many different forms. Usually the number and sequence of switching operations to be performed dictates the contact arrangement.

It is often desirable to introduce time delays by use of relays. One method is to use a thermal relay for a time delay. Due to its simple mechanism, it can be made very small and hermetically sealed, making it ideal for use in aircraft. Because the thermal relay is activated by heat, it can be used on either a.c. or d.c.

Maintenance of Relays

The relay is one of the most dependable electromechanical devices in use, but like any other mechanical or electrical device, relays occasionally wear out or become inoperative for one reason or another. Should relay inspection determine that a relay has exceeded its safe life, the relay should be removed immediately and replaced with another of the same type. Care should be exercised in obtaining the same type replacement because relays are rated in voltage, amperage, type of service, number of contacts, continuous or intermittent duty, and similar characteristics.

For spotting potential relay trouble during preventive maintenance, the following guides are suggested: check for charred or burned insulation on the relay and for darkened or charred terminal leads coming from the relay. Both of these indicate overheating. If there is even a slight indication that the relay has overheated it should be replaced with a new relay of the same type. An occasional cause of relay trouble is not the fault of the relay at all, but is due to overheating caused by the power terminal connectors not being tight enough. This should always be checked during preventive maintenance.

It is recommended that covers not be removed from semisealed relays in the field. Removal of a cover in the field, although it might give useful information to a trained eye, may result in entry of dust or other foreign material which may cause contact discontinuity.

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CHAPTER 4

ELEMENTARY PHYSICS

The Aviation Electrician is associated with some very complex machines and equipment. He is expected to understand, operate, service, and maintain these machines and equipment, and to instruct new men so that they can also perform these functions. No matter how complex a machine or item of equipment is, its action can be satisfactorily explained as an application of a few basic principles of physics. In order to understand, maintain, and repair the equipment and machinery necessary to the operation of the aircraft of the fleet, an understanding of these basic principles is essential. There can be no question that the electrician who possesses this understanding is better equipped to meet the demands placed upon him in his everyday tasks.

Physics is devoted to finding and defining problems, as well as to searching for their solutions. It not only teaches a person to be curious about the physical world, but also provides a means of satisfying that curiosity. The distinction between physics and other sciences cannot be well defined, because the principles of physics also pertain to the other sciences. Physics is a basic branch of science and deals with matter, motion, force, and energy. It deals with the phenomena which arise because matter moves, exerts force, and possesses energy. It is the foundation for the laws governing these phenomena, as expressed in the study of mechanics, hydraulics, magnetism, electricity, heat, light, sound, and nuclear physics. It is closely associated with chemistry and depends heavily upon mathematics for many of its theories and explanations.

MEASUREMENTS

A good understanding of measurements is particularly important to the Aviation Electrician in that much of his professional responsibility will be concerned with some type of measurement. The instruments with which the AE will work include not only meters to measure voltage, current, and resistance, but also aircraft-installed measuring devices such as altimeters, airspeed indicators, position indicators, etc.

In any study of physics, it soon becomes obvious that specific words and terms have specific meanings which must be mastered from the very start. Without an understanding of the exact meaning of the term, there can be no real understanding of the principles involved in the use of that term. Once the term is correctly understood, however, many principles may be discussed briefly to illustrate or to emphasize the particular aspects of interest. The first part of this chapter is devoted to definitions of some physical terms and a brief general discussion of certain principles of vital interest to all personnel.

In order to evaluate results, it is often essential to know how much, how far, how many, how often, or in what direction. As scientific investigations become more complex, measurements must become more accurate, and new methods must be developed to measure new things.

Measurements may be classified into three broad categories—magnitude, direction, and time. These categories are broken down into several types, each with its own standard units. Measurements of direction and time have become fairly well standardized and have comparatively few subdivisions. Magnitude, on the other hand, is an extremely complex category with many classes and subdivisions involved.

The unit of measurement is just as important as the number which precedes it, and both are

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necessary to give an accurate description.

Two widely used sets of measurement units are the metric and the English. The metric units are most often used to express scientific observations where the basic unit of distance is the meter, of mass is the kilogram, and of time is the second. This is called the meter-kilogram-second system, or the mks system. Another widely used metric system uses the centimeter for units of distance, the gram for units of mass, and the second for units of time, and so is called the centimeter-gram-second system, or cgs system. The English system uses the foot for distance, the pound for mass, and the second for time, and so is called the foot-pound-second system, or fps system. See table 4-1 for other units.

METRIC UNITS OF LENGTH

Metric units of length are based on the standard meter which was first intended to be one ten-millionth part of the distance between the earth's Equator and one of the poles. Although more recent measurements show this distance to be close to 10,000,880 meters, the original length of the meter is still accepted as standard.

When large distances are measured it is customary to use the kilometer, which is 1,000 meters: 1 kilometer (km) = 1,000 meters (m). For smaller measurements the meter is divided into smaller units. One meter equals 100 centimeters (1 m = 100 cm) and 1 centimeter equals 10 millimeters (1 cm = 10 mm), so 1 meter equals 1,000 millimeters (1 m = 1,000 mm).

The micron is still smaller, and is used in referring to the size of a particle of foreign matter that may pass through a screen or filter in a hydraulic system. The micron is one-thousandth of a millimeter or one-millionth of a meter, the millimicron is one-thousandth of a micron, and the micromicron is one-thousandth of a millimicron or one millionth of a micron.

ENGLISH UNITS OF LENGTH

The common units of the English system of distance measurement are inches, feet, yards, and miles, where 1 foot equals 12 inches (1 ft = 12 in.), 1 yard equals 3 feet (1 yd = 3 ft = 36 in.) and 1 mile equals 1,760 yards (1 mile = 1,760 yd = 5,280 ft = 63,360 in.). The nautical mile is 6,076.115 feet. The mil is 1/1,000 inch.

In 1866 the United States, by an act of Congress, defined the yard to be 3,600/3,937 part of a standard meter, or in decimal form approximately 0.9144 meter. Thus, other conversions between the systems may be found by proper multiplication or division. Some approximate conversions are listed in table 4-2.

VOLUME

Volume is the amount of space enclosed within the bounding surfaces of a body. To determine the volume of a regularly shaped body, three measurements of length are required—

Volume = length × width × depth (height)
$V = lwh$

Volume is said to have dimensions of length cubed because it is the product of three length measurements. The unit of volume is a cube having edges of unit length. (See fig. 4-1.)

A great deal of ingenuity is often needed to measure the volume of irregularly shaped bodies. Sometimes it is practical to divide a body into a series of regularly shaped parts and then apply the rule that the total volume is equal to the sum of the volumes of all individual parts. Figure 4-2 demonstrates another method of measuring the volume of small irregular bodies. The volume of water displaced by a body submerged in water is equal to the volume of the body.

A somewhat similar consideration is possible for floating bodies. A floating body displaces its own weight of liquid. This may be proved by filling a container to the brim with liquid, then gently lowering the body to the surface of the liquid and catching the liquid that flows over the brim. Weighing the liquid displaced and the original body will prove the truth of the statement.

UNITS OF MASS, WEIGHT, AND FORCE

The measure of the quantity of matter which a body contains is called mass. The mass of a

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Table 4-1.—Frequently used units of measurement

English system	Metric system	General
acre	angstrom	ELECTRICAL
Btu (British thermal unit)	bar	ampere
bushel	calorie	coulomb
dram	dyne	decibel
foot	erg	farad
gallon	gram	henry
hertz	hectare	ohm
horsepower	hertz	volt
hour	hour	watt
inch	joule	LIGHT
knot	liter	candle
mil	meter	candela
mile	metric ton (1,000 kg)	lambert
minute	micron	lumen
ounce	minute	MAGNETIC
peck	newton	gauss
pint	quintal	gilbert
pound	second	maxwell
quart	stere	rel
second		
slug		
ton (short, 2,000 lb long, 2,240 lb)		
yard		

Table 4-2.–Conversion factors for units of length

	km	m	cm	mm	in.	ft	yd	mile
1 km =	1	1,000	100,000	$1 \times 10^{+6}$	39,370	3,280.83	1,093.61	0.621369
1 m =	0.001	1	100	1,000	39.37	3.28083	1.09361	6.214×10^{-4}
1 cm =	1×10^{-5}	0.01	1	10	0.3937	0.032808	1.094×10^{-2}	6.214×10^{-6}
1 mm =	1×10^{-6}	1×10^{-3}	0.1	1	0.03937	3.28×10^{-3}	1.094×10^{-3}	6.214×10^{-7}
1 in. =	2.54×10^{-5}	2.54×10^{-2}	2.54	25.4	1	0.08333	0.02777	1.58×10^{-5}
1 ft =	3.048×10^{-4}	0.3048	30.48	304.8	12	1	0.33333	1.89×10^{-4}
1 yd =	9.144×10^{-4}	0.9144	91.44	914.4	36	3	1	5.68×10^{-4}
1 mile =	1.60934	1,609.34	160,934	1,609,340	63,360	5,280	1,760	1

NOTE: When a number is multiplied by a power of ten, the decimal point is moved the number of places represented by the power. A negative power moves the decimal point to the left; a positive power moves it to the right. Thus, $84 \times 10^{-2} = .84$, and $84 \times 10^{2} = 8,400$. Simply stated, a power of ten merely moves the decimal point left or right.

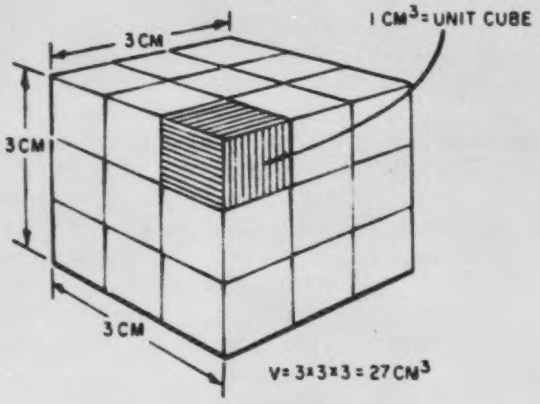

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Figure 4-1.—Volume measurement.

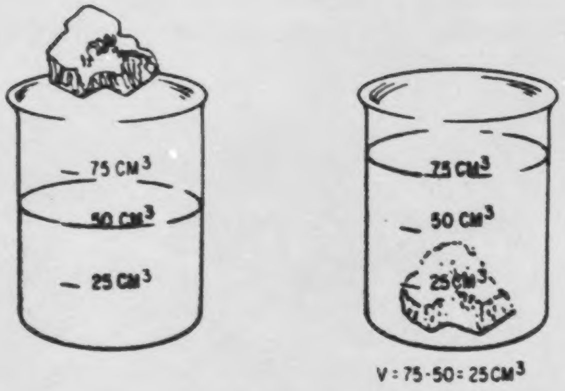

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Figure 4-2.—Measuring the volume of an irregular object.

body does not change. It may be compressed to a smaller volume, or expanded by the application of heat, but the quantity of matter remains the same.

Originally, the metric unit of mass was based on the gram (gm) being equal to the mass of 1 cubic centimeter of pure water at a temperature of 4° Celsius, and for practical purposes this is essentially correct. The U.S. Bureau of Standards has two blocks of platinum which are identical to the standard kilogram (1,000 gm) block of platinum preserved at the International Bureau of Weights and Measures near Paris. The standard pound (lb) is the mass equal to 0.4536 kilograms, or 453.6 grams, at sea level.

The mass of a body is constant no matter where the body is located. Its weight, however, is the force with which it is attracted toward the earth, and becomes less as the body is moved away from the earth's surface.

In addition to grams, kilograms, and pounds being used as units of mass, these same units are also used to describe the weight of a body by comparing the body's weight to the weight of a standard mass unit. Unless otherwise specified, when an object is described as having a weight of 1 pound, it means the object has the same pull of gravity that a mass of 1 pound would have near the earth's sea level. At sea level, the numerical values of weight and mass of a given object are equal when expressed in the same units.

It is interesting to note that spring weighing machines are not legal for trade in most states of the U.S. A spring scale registers the force necessary to overcome the pull which gravitational force exerts on the object being weighed. This gravitational force varies with the altitude of the object on the earth. A balancing scale, usually called a BALANCE, measures mass rather than weight, although the dial is marked in pounds. On a balance, the object to be weighed is compared with a standard unit of mass. The variation due to altitude is canceled because it affects both the standard unit and the object to be weighed. Therefore, the standard mass serves as an accurate unit of measure for all locations on the surface of the earth.

To avoid confusion, the slug is sometimes used as the unit of mass. This is the mass which weighs 32 pounds at sea level. Its relationship to pounds weight and pounds force and the advantage of its use will be discussed in more detail later in this chapter. Also to be discussed are the metric force units of dynes and newtons. At this point, however, it can be said that at sea level a mass of 1 gram (gm) exerts a downward force of 980 dynes due to gravity, and that 1 kilogram (kg) exerts a downward force of 9.8 newtons. Since 1 kg = 1,000 gm, a kilogram exerts a force of 1,000 × 980 dynes or 980,000 dynes, which is equal to 9.8 newtons. Thus 1 newton = 100,000 dynes.

To relate the newton to the English system, 1 newton equals 0.2247 pound force, or 1 pound force equals 4.448 newtons. Also, the mass unit of 1 slug equals the mass of approximately 14.6 kilograms, so 1 kilogram of mass is approximately 0.0686 slug.

Conversion between weight units of the metric system is simple since it is only a matter of moving the decimal point: 1,000 milligrams (mg) = 1 gm; 1,000 gm = 1 kg; and 1,000 kg = 1 metric ton. The English system requires more effort, since the pound is divided into 16 ounces, and the ounce into 16 drams. The "short ton" is 2,000 pounds, while the "long ton" is 2,240 pounds. The metric ton is fairly close to the long ton, converting to 2,205 pounds.

DERIVED UNITS

Units based on combinations of two or three fundamental units can always be expressed as some combination of these units. The watt (unit of power) could be written as joules (unit of work) per second. The joule in turn could be expressed as newtons (force) times meters (distance) and the watt then becomes newton-meters per second. Likewise, the unit of horsepower could be expressed in foot-pounds per second. Although there are conversion factors between derived units of the English system and the metric system, fundamental units of the two systems are not combined. For instance, if force is given in pounds and distance in meters, one or the other must be changed before combining them to get work units.

Speed and Velocity

One example of a derived unit is the knot, a unit of speed. This unit combines the nautical mile as the unit of distance and the hour as the unit of time, and is derived by dividing the distance traveled by the time required. Thus, if an aircraft traveled at a constant rate for 6 minutes (0.1 hr) and moved a distance of 30 nautical miles, its speed would be 30/0.1 or 300 knots. The rate of travel (speed) may also be used to solve for distance traveled when time is known. If the above aircraft traveled 250 knots for 3 hours, it would move 750 nautical miles. Likewise, the time required for moving a certain distance may be determined when the speed is known. A distance of 360 nautical miles traveled at 240 knots would require 360/240 = 1.5 hours, or 1 hour 30 minutes.

Very often speed is expressed with two fundamental units such as miles per hour, kilometers per hour, or feet, inches, meters or centimeters per minute or per second. Conversion is a matter of replacement of one unit by its equivalent in another unit. For example, a speed of 60 miles per hour (60 mph) may be converted to feet per second by replacing the mile with 5,280 feet and the hour with 3,600 seconds. Thus a speed of 60 mph $= \frac{60 \times 5{,}280}{3{,}600 \text{ sec}} = 88$ feet per second.

Table 4-3 gives the conversion factors between meters per second, feet per second, kilometers per hour, miles per hour, and knots.

The terms "speed" and "velocity" are sometimes used as having the same meaning. However, velocity is a vector quantity—that is, it is speed in a given direction. Thus, a car may move around a circular path with a constant speed while its velocity is continuously changing. When a body moves with constant speed along a straight line whose direction is specified, it is customary to speak of its velocity (which is numerically equal to its speed). Moving along a curved path or along a straight path with no reference being made to direction, it is proper to speak of its speed.

Work and Energy

Units of work and energy, also derived units, are the product of the units of force and distance. In the cgs system, the erg is the work done by a force of 1 dyne acting through a distance of 1 centimeter. The joule is the unit of work in the mks system where 1 newton acts through a distance of 1 meter. Since 1 newton equals 100,000 dynes and 1 meter equals 100

Table 4-3.—Conversion factors for speed and velocity

Speed	m/sec	ft/sec	km/hr	mi/hr	knots
1 m/sec =	1	3.281	3.6	2.24	1.94
1 ft/sec =	0.3048	1	1.0973	0.6818	0.5921
1 km/hr =	0.27778	0.9113	1	0.6214	0.5396
1 mi/hr =	0.44704	1.4667	1.6093	1	0.8684
1 knot =	0.5148	1.689	1.853	1.152	1

centimeters, then the joule is equal to 10,000,000 ergs.

In the English system the unit foot-pound is defined as the work done in lifting 1 pound a distance of 1 foot against the force of gravity. Thus the work done in lifting a mass of 5 pounds vertically 4 feet is 5 lb X 4 ft = 20 foot-pounds. (Do not confuse this foot-pound with the one used to measure torque.) Since 1 pound force equals 4.448 newtons, and 1 foot equals 0.3048 meter, then 1 foot-pound is approximately 1.356 joules.

The calorie is the heat energy required to raise the temperature of 1 gram of water 1° Celsius. The Btu (British thermal unit) is the heat energy required to raise the temperature of 1 pound of water 1° Fahrenheit, and is equivalent to 252 calories (and, incidentally, to 777.8 foot-pounds of mechanical energy).

Power

All units of power include measurements of force, distance, and time, because power equals work (which is force times distance) divided by time. The watt is the unit of power frequently used with electrical units, but is also the rate of doing 1 joule of work in 1 second. Thus, if a force of 5 newtons acts through a distance of 12 meters in 3 seconds, the power required is $P = \frac{5 \times 12}{3} = 20$ watts. If the same work is to be done in 2 seconds, 30 watts will be required.

The horsepower is a larger unit of power and is equal to 550 foot-pounds per second, or 746 watts; therefore, 1 foot-pound per second is 746/550 watts, or about 1.356 watts.

TEMPERATURE

If an object is hot to the touch, it is said to have a "high" temperature. If it is cold to the touch, it has a "low" temperature. In other words, temperature is used as a measure of the hotness or coldness of an object being described. However, hotness and coldness are only relative. For example, on a cold day, metals seem colder to the touch than nonmetals because they conduct heat away from the body more rapidly. Also, upon leaving a warm room the outside air seems cooler than it really is. Going from the outside cold into the warm room, the room seems warmer than it really is. In other words, the temperature a person feels depends upon the state of his body.

Temperature Conversion

There are many systems of temperature measurement; it is frequently necessary to convert from one to the other. The four most common scales in use today are the Fahrenheit (F), Celsius (C), Rankine (R), and Kelvin (K). The Celsius scale was formerly known as the centigrade scale, but was renamed to Celsius scale in recognition of Andus Celsius, the Swedish astronomer who devised it.

FAHRENHEIT SCALE.–The most familiar scale to most Americans is the Fahrenheit scale which was established so that its zero point approximates the temperature produced by mixing equal quantities by weight of snow and common salt.

Under standard atmospheric pressure, the boiling point of water is 212 degrees above zero and the freezing point 32 degrees above zero. Each degree represents an equal division, and there are 180 such divisions between freezing and boiling.

CELSIUS SCALE.–This scale uses the freezing point and boiling point of water under standard atmospheric pressure as fixed points of 0 and 100, respectively, with 100 equal divisions between. These 100 divisions represent the same difference in temperature as 180 divisions of the Fahrenheit scale. This ratio of 100/180 reduces to 5/9, which means a change of 1° F is equal to a change of 5/9° C. A change of 5° on the Celsius scale, therefore, is equal to a change of 9° on the Fahrenheit scale. Because 0 on the Celsius scale corresponds to 32° on the Fahrenheit scale, a difference in reference points exists between the two scales. (See fig. 4-3.)

To convert from the Fahrenheit scale to the Celsius scale, subtract the 32° difference and multiply the result by 5/9. As an example, convert 68° Fahrenheit to Celsius–

$$\frac{5}{9}(68 - 32) = \frac{5}{9} \times 36 = 20^\circ \text{ C}$$

To convert Celsius to Fahrenheit, the reverse procedure is necessary. First multiply the reading on the Celsius thermometer by 9/5 and then add 32 to the result–

$$\frac{9}{5}(20) + 32 = 36 + 32 = 68^\circ \text{ F}$$

One way to remember when to use 9/5 and when to use 5/9 is to keep in mind that the Fahrenheit scale has smaller divisions than the Celsius scale. In going from Celsius to Fahrenheit, multiply by the ratio that is larger; in going from Fahrenheit to Celsius, use the smaller ratio.

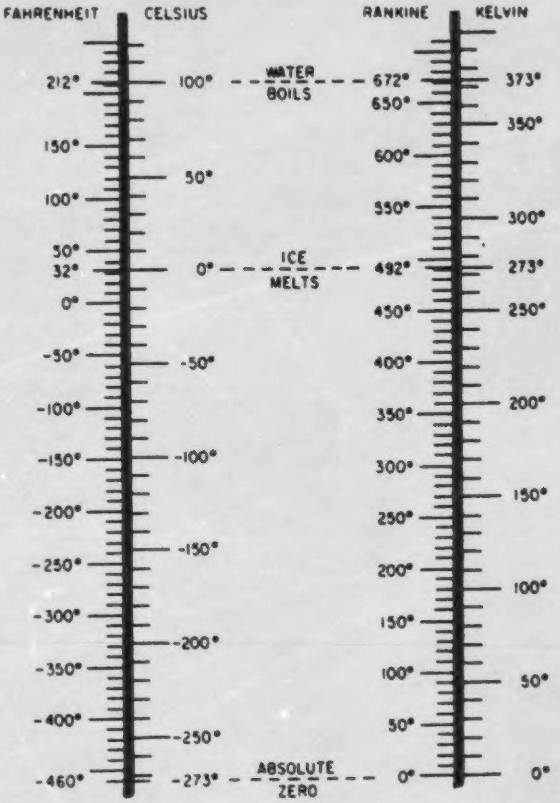

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Figure 4-3.–Comparison of the four common temperature scales.

Another method of temperature conversion which uses these same ratios is based on the fact that the Fahrenheit and Celsius scales both register the same temperature at -40°; that is, -40° F equals -40° C. This method of conversion, sometimes called the "40 rule," proceeds as follows:

1. Add 40 to the temperature which is to be converted. Do this whether the given temperature is Fahrenheit or Celsius.
2. Multiply by 9/5 when changing Celsius to Fahrenheit; by 5/9 when changing Fahrenheit to Celsius.
3. Subtract 40 from the result of step 2. This is the answer.

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As an example to show how the 40 rule is used, convert 100° C to the equivalent Fahrenheit temperature:

$$100 + 40 = 140$$
$$140 \times 9/5 = 252$$
$$252 - 40 = 212$$

Therefore, 100° C = 212° F. Remember that the multiplying ratio for converting F to C is 5/9, rather than 9/5. Also remember to always ADD 40 first, then multiply, then SUBTRACT 40, regardless of the direction of the conversion.

It is important that all electricians be able to read thermometers and to convert from one scale to the other. In some types of electrical equipment, thermometers are provided as a check on operating temperatures. Thermometers are also used to check the temperature of a charging battery. Aircraft-installed outside air temperature gages normally indicate in degrees Celsius and it may be necessary to convert to degrees Fahrenheit to calibrate fuel quantity systems or perform other maintenance.

KELVIN SCALE.–Also known as the absolute scale, the Kelvin scale has as its zero point the temperature which has been indicated by experiments with hydrogen as the point where all molecular motion would cease and no additional heat could be extracted from the substance. Theoretically, this is referred to as absolute zero temperature. This point is -273.16° C, but -273° C is used for most calculations as shown on figure 4-3. The spacing between degrees is the same as for the Celsius scale, and so conversion to Kelvin temperature is made by adding 273 to the Celsius temperature.

RANKINE SCALE.–This scale has the same spacing between degrees as the Fahrenheit scale, but has its zero corresponding to 0° K (absolute zero). This is calculated to be -459.69° F, but -460° F is usually used. To convert Fahrenheit to Rankine, add 460 to the Fahrenheit temperature.

Since Rankine and Kelvin both have the same zero point, conversion between the two scales requires no addition or subtraction. Rankine temperature is equal to 9/5 times Kelvin temperature, and Kelvin temperature is equal to 5/9 times Rankine temperature.

Formulas may be derived for converting between Fahrenheit and Kelvin and between Celsius and Rankine from the information already given, but since they are less frequently needed are not included here.

Thermometers

The measurement of temperature is known as THERMOMETRY. Many modern thermometers use liquids in sealed containers. Water was the first liquid used, but because it freezes at 0° C it could not measure temperatures below that point. After much experimentation, scientists decided that the best liquids to use in the construction of thermometers are alcohol and mercury because of the low freezing points of these liquids.

LIQUID THERMOMETERS.–The construction of the common laboratory thermometer gives some idea as to the meaning of a change of 1° in temperature. A bulb is blown at one end of a piece of glass tubing of small bore. The tube and bulb are then filled with the liquid to be used. The temperature of both the liquid and the tube during this process are kept at a point higher than the thermometer will reach in normal usage. The glass tube is then sealed and the thermometer is allowed to cool. During the cooling process, the liquid falls away from the top of the tube and creates a vacuum within the thermometer.

For marking, the thermometer is placed in melting ice. The height of the liquid column is marked as the 0° C point. Next, the thermometer is placed in steam at a pressure of 76 centimeters of mercury and a mark is made at that point to which the liquid inside rises. That is the boiling point, or the 100° C mark. The space between these two marks is then divided into 100 equal parts. These spacings are known as DEGREES. It is this type of thermometer that is used almost exclusively in laboratory work and in testing electrical equipment, and is known as the Celsius thermometer which was mentioned earlier.

SOLID THERMOMETERS.–Because the range of all liquid thermometers is extremely limited, other methods of thermometry are necessary. Most liquids freeze at temperatures between 0° and -200° Celsius. At the upper end of the temperature range where high heat levels are encountered, the use of liquid thermometers is limited by the high vapor pressures of those liquids. Among the most widely used types of thermometers, other than the standard liquid thermometers, are the resistance thermometer and the thermocouple.

The RESISTANCE THERMOMETER makes use of the fact that the electrical resistance of metals changes as the temperature changes. This type thermometer is usually constructed of platinum wire wound on a mica form and enclosed in a thin-walled silver tube. It is extremely accurate from the lowest temperature to the melting point of the unit.

The THERMOCOUPLE shown in figure 4-4 is essentially an electric circuit. Its operation is based on the principle that when two unlike metals are joined and the junction is at a different temperature from the remainder of the circuit, an electromotive force is produced. This electromotive force can be measured with great accuracy by a galvanometer. Thermocouples can be located wherever measurement of the temperature is important, and wires run to a galvanometer located at any convenient point. By means of a rotary selector switch, one galvanometer can read the temperatures of thermocouples at any of a number of widely separated points. Also several thermocouples can be connected in parallel to supply an average voltage to an indicator, as is done with jet engine temperature indicating systems.

The principle of the compound bar (fig. 4-5) is also used in thermometers. The bar may be in the shape of a spiral, or perhaps a helix, so that within a given enclosure a greater length of the compound bar may be used, thereby increasing the movement of the free end per degree of temperature change. Also, the indicating pointer may be joined to the moving end of the compound bar by means of distance-multiplying linkage to make the thermometer easier to read. Often this linkage is arranged to give circular movement to the pointer.

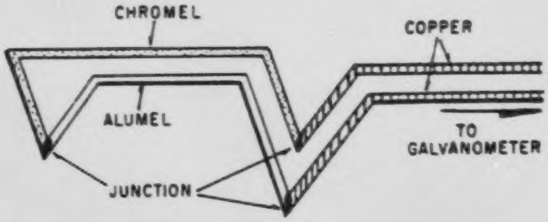

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Figure 4-4.–Thermocouple.

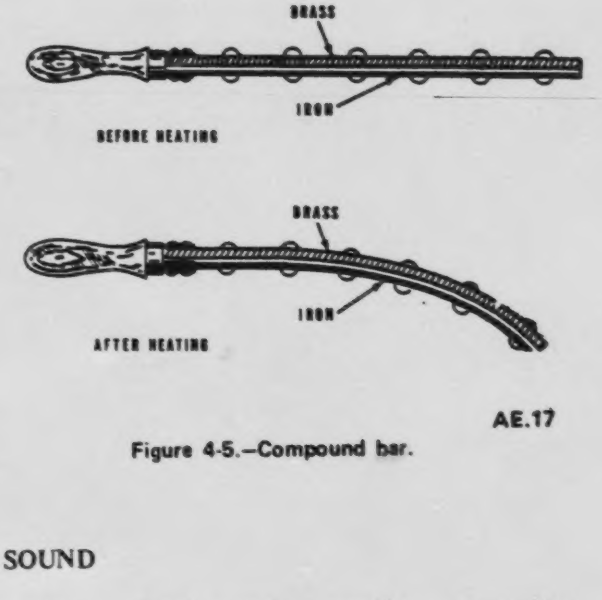

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Figure 4-5.–Compound bar.

SOUND

The methods used to produce, transmit, detect or measure sound are not as important to the AE as they are to many other ratings which deal directly with those facets of sound. The AE, however, working on and around aircraft and other noise generating devices, must always be aware of the personal hazards associated with sound. Chapter 2 of this manual includes a discussion of these safety hazards, and in this chapter only the definitions associated with the measurement of sound will be discussed.

Measurement of Sound

The range of sound that the human ear can detect varies with the individual. The normal range extends from about 20 to 20,000 vibrations per second.

The human ear is a nonlinear unit that functions on a logarithmic basis.

If the ear is tested with tones of any one frequency, the threshold of audibility is reached when intensity is reduced to a sufficiently low level so that auditory sensation ceases. On the other hand, the threshold of feeling is reached when intensity is increased to a sufficiently high level so that the sound produces the sensation of feeling and becomes painful. If this procedure is performed over a wide frequency range, the data can be used to plot two curves—one for the lower limit of audibility and the other for the maximum auditory response (fig. 4-6). Below the lower curve, the sound is too faint to be audible. Above the upper curve, the sensation is one of feeling rather than of hearing; that is, the sensation of sound is masked by that of pain. The area between the two curves shows the pressure ranges for auditory response at various frequencies. Note that the scales of frequency and pressure are nonlinear. An advance of one horizontal space doubles the frequency, and an advance of one vertical space multiplies the pressure by ten.

SOUND UNITS.—The loudness of sound is not measured by the same type of scale used to measure length. Units of sound measurement are used that vary nonlinearly with the amplitude of the sound variations. These units are the bel and decibel, which refer to the difference between sounds of unequal intensity or sound levels. The decibel, which is one-tenth of a bel, is the minimum change of sound level perceptible to the human ear. Hence, the decibel merely describes the ratio of two sound levels. A sound for which the power is 10 times as great as that of another sound level differs in power level by 1 bel, or 10 decibels; thus, 5 decibels may represent almost any volume of sound, depending on the intensity of the reference level or the sound level on which the ratio is based.

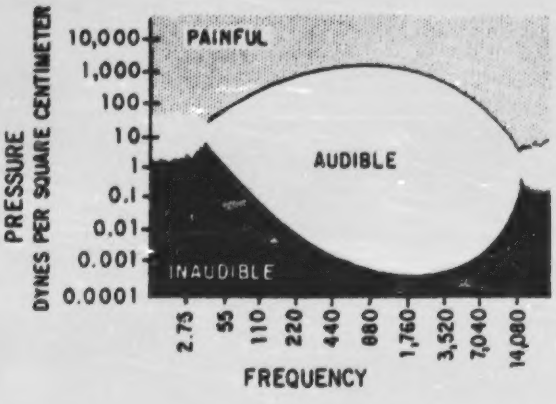

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Figure 4-6.—Field of audibility.

INTENSITY LEVEL.—An arbitrary zero reference level is used to accurately describe the loudness of various sounds. This zero reference level is the sound produced by 10^{-16} watts per square centimeter of surface area facing the source. This level approximates the least sound perceptible to the ear and is usually called the threshold of audibility. Thus, the sensation experienced by the ear when subjected to a noise of 40 decibels above the reference level would be 10,000 times as great as when subjected to a sound that is barely perceptible.

STRUCTURE OF MATTER

All matter is composed of atoms, and these atoms are, in turn, composed of smaller subatomic particles. The subatomic particles of major interest in elementary physics are the electron, the proton, and the neutron. They may be considered electrical in nature, with the proton representing a positive charge, the electron representing a negative charge, and the neutron being neutral (neither positive nor negative). Although in general the composition of matter follows a consistent pattern for all atoms, the detailed arrangement of subatomic particles is different for each distinct substance. It is the combination and arrangement of the subatomic particles which imparts distinguishing chemical and physical characteristics to a substance.

The protons and the neutrons of an atom are closely packed together in a nucleus (core), with the electrons revolving around the nucleus (fig. 4-7). Atoms are normally considered to be electrically neutral—that is, they normally contain an equal number of electrons and protons but this condition does not actually prevail under all circumstances. Atoms which contain an equal number of electrons and protons are called balanced atoms; those with an excess or a deficiency of electrons are called "ions."

The proton and the neutron have approximately the same mass, which is approximately 1,836 times the mass of an electron. In any atom, nearly all the mass is contained in the nucleus. It may be assumed that under normal conditions any change in the composition of the atom would involve a change in the number or arrangement of the electrons. This assumption is generally correct—the most notable exception being in the field of nuclear physics, or nucleonics. In chemistry and in general physics (including electricity and electronics), it is the electron complement that is of major concern.

ELEMENTS

The word element denotes any one of about 100 natural substances, such as iron, which comprise the basic substance of all matter. Two or more elements may combine chemically to form a compound; any combination which does not result in a chemical reaction between the different elements is called a mixture.

The atom is the smallest unit that exhibits the distinguishing characteristics of an element. An atom of any one element differs from an atom of any other element in the number of protons in the nucleus. All atoms of a given element contain the same number of protons. Thus, it may be seen that the number of protons in the nucleus determines the type of matter.

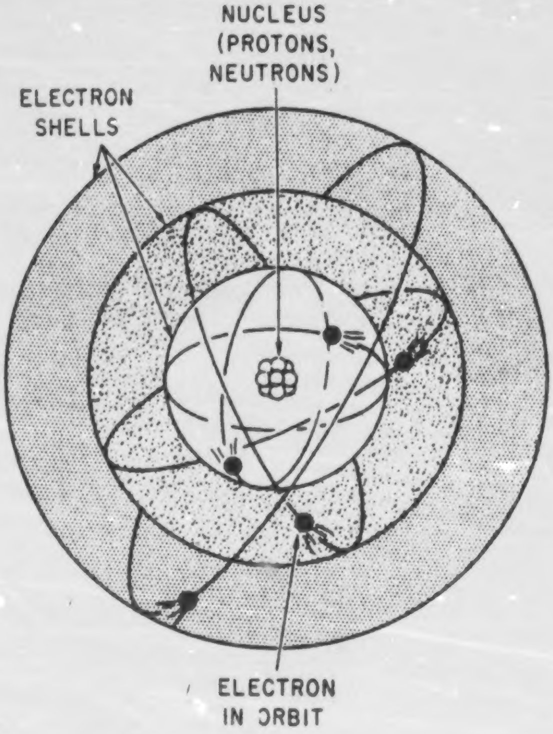

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Figure 4-7.—An atom.

The various elements are frequently tabulated according to the number of protons. The number of protons in the nucleus of the atom is referred to as the atomic number of the element.

Nucleus

The study of the nucleus of the atom is known as nucleonics or nuclear physics, and is the subject of extensive modern investigation. Experiments on nuclei usually involve the bombardment of the nucleus of an atom, using various types of nuclear particles. By this method the composition of the nucleus is changed, usually resulting in the release of energy. The change to the nucleus may occur as

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an increase or a decrease in the number of protons and/or neutrons.

If the number of protons is changed, the atom becomes an atom of a different element. This process, called "transmutation," is the process sought by the alchemists of the middle ages in their attempts to change various metals into gold. Scientists of that period believed transmutation could be accomplished by chemical means–hence the impetus given to the development of chemistry.

If, on the other hand, only the number of neutrons in the nucleus is changed, the atom remains an atom of the same element. Although all the atoms of any particular element have the same number of protons (atomic number), atoms of certain elements may contain various numbers of neutrons. Hydrogen, the sole exception to the rule that all atoms are composed of three kinds of subatomic particles, normally contains a single proton and a single electron–and no neutrons. However, some hydrogen atoms do contain a neutron. Such atoms (although they are atoms of hydrogen) are known as deuterium, or "heavy hydrogen." They are called "heavy" because the addition of the neutron has approximately doubled the weight of the atom. Deuterium figured prominently in the research which led to the development of nuclear energy and the atomic bomb. The atomic weight of an atom is an indication of the total number of protons and neutrons in the atomic nucleus.

Atoms of an element which have atomic weights which differ from other atoms of that element are called isotopes. Nearly all elements have several isotopes; some are very common, and some are very rare. A few of the isotopes occur naturally. Most of those produced by nuclear bombardment are radioactive or have unstable nuclei. These unstable isotopes undergo a spontaneous nuclear bombardment which eventually results in either a new element or a different isotope of the same element. The rate of spontaneous radioactive decay is measured by "half-life" which is the time required for one-half the atoms of a sample of radioactive material to change (by spontaneous radioactive decay) into a different substance. Uranium, after a few billion years and several substance changes, becomes lead.

Electron Shells

The physical and chemical characteristics of an element are determined by the number and distribution of electrons in the atoms of that element. The electrons are arranged in successive groups of electron shells of rotation around the nucleus; each shell can contain no more than a specific number of electrons. An INERT element (that is, one of the few gas elements which do not combine chemically with any other element) is a substance in which the outer electron shell of each atom is completely filled. All other elements are active, and one or more electrons are missing from the outer shell. An atom with only one or two electrons in its outer shell can be made to give up those electrons; an atom whose outer shell needs only one or two electrons to be completely filled can accept electrons from another element which has one or two "extras."

The concept of "needed" or "extra" electrons arises from the basic fact that all atoms have a tendency toward completion (filling) of the outer shell. An atom whose outer shell has only two electrons may have to collect six additional ones (no easy task, from an energy standpoint) in order to have the eight required for that shell to be full. A much easier way to achieve the same objective is to give up the two electrons in the outer shell and let the full shell next to it serve as the new outer shell. In chemical terminology, this concept is called valence, and is the prime determining factor in predicting chemical combinations.

COMPOUNDS AND MIXTURES

Under certain conditions, two or more elements can be brought together in such a way that they unite chemically to form a COMPOUND. The resulting substance may differ widely from any of its component elements; for example, ordinary drinking water is formed by the chemical union of two gases–hydrogen and oxygen. When a compound is produced, two or more atoms of the combining elements join chemically to form the MOLECULE that is typical of the new compound. The molecule is the smallest unit that exhibits the distinguishing characteristics of a compound.

The combination of sodium and chlorine to form the chemical compound sodium chloride (common table salt) is a typical example of the formation of molecules. Sodium is a highly caustic poisonous metal containing eleven electrons; its outer shell consists of a single electron, which may be considered "extra" (a valence of +1). Chlorine, a highly poisonous gas with seventeen electrons, "lacks" a single electron (has a valence of -1) to fill its outer shell. When the atom of sodium gives up its extra electron, it becomes a positively charged ion. (It has lost a unit of negative charge.) The chlorine, having taken on this extra unit of negative charge (electron) to fill its outer shell, becomes a negative ion. Since opposite electric charges attract, the ions stick together to form a molecule of the compound sodium chloride.

The attracting force which holds the ions together in the molecular form is known as the "valence bond," a term which is frequently encountered in the study of transistors.

Note that in the chemical combination, there has been no change in the nucleus of either atom; the only change has occurred in the distribution of electrons between the outer shells of the atoms. Also note that the total number of electrons has not changed, although there has been a slight redistribution. Therefore, the molecule is electrically neutral, and has no resultant electrical charge.

Not all chemical combinations of atoms are on a one-for-one basis. In the case of drinking water, two atoms of hydrogen (valence of +1) are required to combine with a single atom of oxygen (valence of -2) to form a single molecule of water. Some of the more complex chemical compounds consist of many elements with various numbers of atoms of each. All molecules, like all atoms, are normally considered to be electrically neutral. There are some exceptions to this rule, however, with specific cases of interest being the chemical activity in batteries.

Elements or compounds may be physically combined without necessarily undergoing any chemical change. Grains of finely powdered iron and sulfur stirred and shaken together retain their own identity as iron or sulfur. Salt dissolved in water is not a compound; it is merely salt dissolved in water. Each chemical substance retains its chemical identity, even though it may undergo a physical change. This is the typical characteristic of a MIXTURE.

STATES OF MATTER

In their natural condition, forms of matter are classified and grouped in many different ways. One such classification is in accordance with their natural state—solid, liquid, or gas. This classification is important because of the common characteristics possessed by substances in one group which distinguish them from substances in the other groups. However, the usefulness of the classification is limited by the fact that most substances can be made to assume any of the three forms.

In all matter, the molecules are assumed to be in constant motion, and it is the extent of this motion that determines the state of matter. The moving molecular particles in all matter possess kinetic energy of motion. The total of this kinetic energy is considered to be the equivalent of the quantity of heat in a sample of the substance. When heat is added, the energy level is increased, and molecular agitation (motion) is increased. When heat is removed, the energy level decreases, and molecular agitation diminishes.

In solids, motion of the molecules is greatly restricted by the rigidity of the crystalline structure of the material. In liquids, molecular motion is somewhat less restricted, and the substance as a whole is permitted to "flow." In gases, molecular motion is almost entirely random—the molecules are free to move in any direction and are almost constantly in collision both among themselves and with the surfaces of the container.

This topic and some of its more important implications are discussed in detail under the heading "Heat" in a later section of this chapter.

Solids

The outstanding characteristic of a solid is the tendency to retain its size and shape. Any change in these values requires an exchange of energy. The common properties of a solid are cohesion and adhesion, tensile strength, ductility, malleability, hardness, brittleness, and elasticity. Ductility is a measure of the ease with which the material can be drawn into a wire. Malleability refers to the ability of some materials to assume a new shape when pounded. Hardness and brittleness are self-explanatory terms. The remaining properties are discussed in more detail in the following paragraphs.

COHESION AND ADHESION.–Cohesion is the molecular attraction between like particles throughout a body, or the force that holds any substance or body together. Adhesion is the molecular attraction existing between surfaces of bodies in contact, or the force which causes unlike materials to stick together.

Cohesion and adhesion are possessed by different materials in widely varying degree. In general, solid bodies are highly cohesive but only slightly adhesive. Fluids (liquids and gases), on the other hand, are usually quite highly adhesive but only slightly cohesive. Generally a material having one of these properties to a high degree will possess the other property to a relatively low degree.

TENSILE STRENGTH.–The cohesion between the molecules of a solid explains the property called tensile strength. This is a measure of the resistance of a solid from being pulled apart. Steel possesses this property to a high degree, and is thus very useful in structural work. When a break does occur, the pieces of the solid cannot be stuck back because merely pressing them together does not bring the molecules into close enough contact to restore the molecular force of cohesion. However, melting the edges of the break (welding) allows the molecules on both sides of the break to flow together, thus bringing them once again into the close contact required for cohesion.

ELASTICITY.–If a substance will spring back to its original form after being deformed, it has the property of elasticity. This property is desirable in materials to be used as springs. Airspeed indicators and altimeters are examples of instruments that depend on the elasticity of certain types of metal to provide critical information to the pilot of an aircraft.

Elasticity of compression is exhibited to some degree by all solids, liquids, and gases; the closeness of the molecules in solids and liquids makes them hard to compress, but gases are easily compressed because the molecules are farther apart.

Liquids

The outstanding characteristic of a liquid is its tendency to retain its own volume while assuming the shape of its container; thus a liquid is considered almost completely flexible and highly fluid.

Liquids are practically incompressible; applied pressure is transmitted through them instantaneously, equally, and undiminished to all points on the enclosing surfaces. Hydraulic apparatus can be used to increase or to decrease input forces, thus providing an action similar to that of mechanical advantage in mechanical systems. Because of these properties, hydraulic servomechanisms have advantages as well as disadvantages and limitations when compared with other systems.

The fluidity of hydraulic liquids permits the component parts of the system to be placed conveniently at widely separated points when necessary. Hydraulic power units can transmit energy around corners and bends without the use of complicated gears and levers. They operate with a minimum of slack and friction, which are often excessive in mechanical linkages. Uniform action is obtained without vibration, and the operation of the system remains largely unaffected by variations in load. The accumulator (which provides the necessary pressurization of a hydraulic system to furnish practically instantaneous response) can be pressurized during periods of nonaction, thus eliminating the "buildup time" characteristic of electric servos.

However, the hydraulic hoses which transmit the fluid from unit to unit are bulky and heavy compared to electric wiring. Many of the hydraulic fluids in common usage are messy and constitute safety hazards. They contribute to the danger of slipping, they cause deterioration of the insulation on electric wiring, they conduct electricity and thus increase the hazards of short circuiting, and some are flammable.

Gases

The most notable characteristic of a gas is the tendency to assume not only the shape but also the volume of its container, and the definite relationship that exists between the volume, pressure, and temperature of a confined gas.

The ability of a gas to assume the shape and volume of its container is the result of its extremely active molecular particles, which are free to move in any direction. Cohesion between molecules of a gas is extremely small, so the molecules tend to separate and distribute themselves uniformly throughout the volume of the container. In an unpressurized container of liquid, pressure is exerted on the bottom and the sides of the container up to the level of the liquid. In a container of gas, however, the pressure is also exerted against the top surface, and the pressure is equal at all points on the enclosing surfaces.

The relationship of volume, pressure, and temperature of a confined gas are explained by Boyle's law, Charles' law, and the general law for gases.

Many laboratory experiments based on these laws make use of the ideas of "standard pressure" and "standard temperature." These are not natural standards, but are standard values selected for convenience in laboratory usage. Standard values are generally used at the beginning of an experiment, or when a temperature or a pressure is to be held constant. Standard temperature is 0° C, the temperature at which pure ice melts. Standard pressure is the pressure exerted by a column of mercury 760 millimeters high. In many practical uses these standards must be changed to other systems of measurement.

All calculations based on the laws of gases make use of "absolute" temperature and pressure. These topics require a somewhat more detailed explanation.

GAS PRESSURE.–Gas pressure may be indicated in either of two ways–absolute pressure or gage pressure. Since the pressure of an absolute vacuum is zero, any pressure measured with respect to this reference is referred to as "absolute pressure." In the present discussion, this value represents the actual pressure exerted by the confined gas.

At sea level the average atmospheric pressure is approximately 14.7 pounds per square inch (psi). This pressure would, in a mercurial barometer, support a column of mercury 760 millimeters in height. Thus, normal atmospheric pressure is the standard pressure mentioned previously.

However, the actual pressure at sea level varies considerably; and the pressure at any given altitude may differ from that at sea level. Therefore, it is necessary to take into consideration the actual atmospheric pressure when converting absolute pressure to gage pressure (or vice versa).

When a pressure is expressed as the difference between its absolute value and that of the local atmospheric pressure, the measurement is designated "gage" pressure, and is usually expressed in "pounds per square inch gage" (psig). Gage pressure may be converted to absolute pressure by adding the local atmospheric pressure to the gage pressure.

ABSOLUTE ZERO.–Absolute zero, one of the fundamental constants of physics, is usually expressed in terms of the Celsius scale. Its most predominant use is in the study of the kinetic theory of gases. In accordance with the kinetic theory, if the heat energy of a given gas sample could be progressively reduced, some temperature should be reached at which the motions of the molecules would cease entirely. If accurately determined, this temperature could then be taken as a natural reference, or a true "absolute zero" value.

BOYLE'S LAW.–The English scientist Robert Boyle was among the first to study what he called the "springiness of air." By direct measurement he discovered that when the temperature of an enclosed sample of gas was kept constant and the pressure doubled, the volume was reduced to half the former value; as the applied pressure was decreased, the resulting volume increased. From these observations, he concluded that for a constant temperature the product of the volume and pressure of an enclosed gas remains constant. Boyle's law is normally stated: "The volume of an enclosed

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dry gas varies inversely with its pressure, provided the temperature remains constant."

In equation form, this relationship may be expressed either

$$V_1P_1 = V_2P_2, \text{ or}$$

$$\frac{V_1}{V_2} = \frac{P_2}{P_1}$$

where V_1 and P_1 are the original volume and pressure, and V_2 and P_2 are the revised volume and pressure.

Although not strictly considered an enclosed gas, the air pressure sensed by the pressure altimeter will illustrate the use of Boyle's law. The altimeter contains a bellows which is sealed at a constant pressure, usually sea level pressure, and is called an aneroid. As the aircraft increases altitude the pressure outside of the aneroid decreases, which allows the volume of air inside the aneroid to expand (increase the distance between molecules), which increases the volume of the fixed mass of air. As the volume increases, the pressure inside the aneroid decreases until it equals the pressure outside the aneroid. (Thus, referring to Boyle's law, as the volume increases, the pressure decreases.) The expansion of the aneroid is measured and, through a series of gears, is calibrated to indicate an increase in altitude.

CHARLES' LAW.–The French scientist Jacques Charles provided much of the foundation for the modern kinetic theory of gases. He found that all gases expand and contract in direct proportion to the change in the absolute temperature, provided the pressure is held constant. Expressed in equation form, this part of the law may be expressed

$$V_1T_2 = V_2T_1, \text{ or}$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

where V_1 and V_2 refer to the original and final volumes, and T_1 and T_2 indicate the corresponding absolute temperatures.

Since any change in the temperature of a gas causes a corresponding change in volume, it is reasonable to expect that if a given sample of a gas were heated while confined within a given volume, the pressure should increase. By actual experiment, it was found that the increase in pressure was approximately 1/273 of the 0° C pressure for each 1° C increase. Because of this fact, it is normal practice to state this relationship in terms of absolute temperature. In equation form, this part of the law becomes

$$P_1T_2 = P_2T_1, \text{ or}$$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

In words, this equation states that with a constant volume, the absolute pressure of a gas varies directly with the absolute temperature.

The principles of Charles' law may be illustrated by studying the problems incurred in trying to measure a quantity of aircraft fuel. Some of the very early aircraft had the fuel tank outside the windscreen directly in front of the pilot. Measuring the volume was simple–a rod with a cork or float was inserted inside the tank. When the tank was full, the rod protruded high above the tank, and as the volume decreased the rod disappeared into the tank. By knowing the inside dimensions of the tank, the pilot knew the approximate volume of fuel remaining.

Obviously this method of measuring fuel is unrealistic in our modern aircraft. The energy developed by an engine is determined by the mass of the fuel it uses rather than by the volume, and more fuel can go into the same volume of space on a cold day than on a hot day. A single gallon of JP-4 jet fuel under standard day conditions–15° C (59° F) and 29.92 in./Hg (14.7 lbs/sq in.) at sea level–will weigh approximately 6.5 pounds. If the temperature of the fuel increases to approximately 50° C (122° F), one gallon of JP-4 will weigh approximately 6.3 pounds. This 0.2 pound does not disappear, but because the molecules become more active and the space between the molecules increases, the same mass of fuel occupies more than one gallon of space. Thus, referring to Charles' law, if the temperature increases, the volume must also increase to contain the same amount of mass.

The importance of this variation in the weight of fuel becomes apparent when one considers large quantities such as 10,000 gallons which may be used in large transport or patrol aircraft. Expansion and contraction can cause the aircraft's fuel to vary in weight by 2,000 pounds (a ton of fuel) or more. In an extremely cold climate, it can cause the aircraft to exceed its maximum gross weight. In an extremely warm climate, the reduced tank capacity may cause critically reduced range. The methods used to measure fuel quantity and to compensate for nonstandard conditions are discussed in chapter 15 of this manual.

GENERAL GAS LAW.–The facts concerning gases discussed in the preceding sections are summed up and illustrated in figure 4-8. Boyle's law is expressed in (A) of the figure, while the effects of temperature changes on pressure and volume (Charles' law) are illustrated in (B) and (C), respectively.

By combining Boyle's and Charles' laws, a single expression can be derived which states all the information contained in both. This expression is called the GENERAL GAS EQUATION, a very useful form of which is given by the following equation. (NOTE: the capital P and T signify absolute pressure and temperature, respectively.)

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

It can be seen by examination of figure 4-8 that the three equations are special cases of the general equation. Thus, if the temperature remains constant, T_1 equals T_2 and both can be eliminated from the general formula, which then reduces to the form shown in (A). When the volume remains constant, V_1 equals V_2, thereby reducing the general equation to the form given in (B). Similarly, P_1 is equated to P_2 for constant pressure, and the equation then takes the form given in (C).

It should be understood that the general gas law applies only when one of the three measurements remains constant. When a gas is compressed, the work of compression is done upon the gas. Work energy is converted to heat energy in the gas so that dynamical heating of the gas takes place. Experiments have shown that when air at 0° C is compressed in a nonconducting cylinder to half its original volume, its rise in

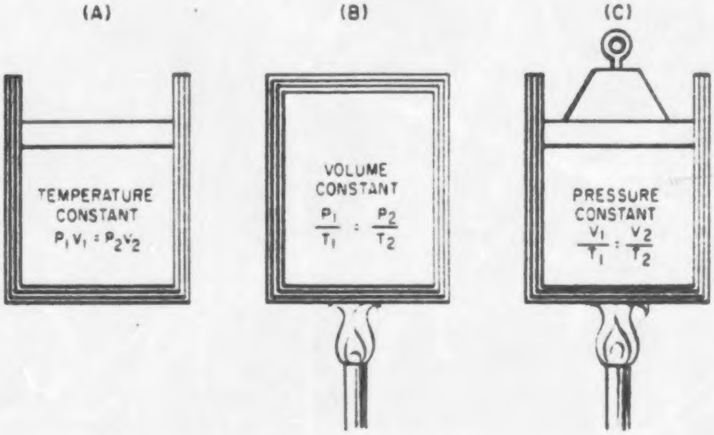

Figure 4-8.–The general gas law.

temperature is 90° C, and when compressed to one-tenth, its rise is 429° C.

The general gas law applies with exactness only to "ideal" gases in which the molecules are assumed to be perfectly elastic. However, it describes the behavior of actual gases with sufficient accuracy for most practical purposes.

MATTER AND ENERGY

MATTER as already discussed may be defined basically as "anything that occupies space and has weight or mass." Matter may be changed or combined by various methods–physical, chemical, or nuclear. Matter has many properties; properties possessed by all forms of matter are called general properties, while those properties possessed only by certain classes of matter are referred to as special properties.

ENERGY may be defined basically as "the capacity for doing work." It may be classified in many ways; but for this discussion, energy will be classified as mechanical, chemical, radiant, heat, light, sound, electrical, or magnetic. Energy is constantly being exchanged from one object to another and from one form to another.

Law of Conservation

Matter may be converted from one form to another with no change in the total amount of matter. Energy may also be changed in form with no resultant change in the total quantity of energy. In addition, a third statement has been added within the past half century: "Although the total amount of matter and energy remains constant, matter can be converted into energy or energy into matter." This statement is known as the law of conservation for energy and matter.

The destruction of matter creates energy, and creation of matter requires expenditure of energy. From this observation it may be implied that a given quantity of matter is the equivalent of some amount of energy. In common usage it is usually stated that matter "possesses" energy. For example, aviation gasoline contains energy to produce heat to make an engine run.

General Properties of Matter

Matter, in all forms, possesses certain properties. In the basic definition it has been stated that matter occupies space and has mass. Those two ideas contain most, if not all, of the general properties of matter.

SPACE.–The amount of space occupied by, or enclosed within, the bounding surfaces of a body is called volume. In the study of physics, this concept must be somewhat modified in order to be completely accurate. Matter may appear as a solid, as a liquid, or as a gas–each having special properties. In a later section of this chapter it will be shown that for even a specific substance the volume may vary with changes in circumstances. It will also be shown that liquids and solids tend to retain their volume when physically moved from one container to another, while gases tend to assume the volume of the container.

In order to clarify our concept of "occupying space," we must deal with minute particles of matter, which are in turn composed of still smaller particles separated from each other by empty space which contains no matter. This idea is used to explain two general properties of matter–impenetrability and porosity.

Two objects cannot occupy the same space at the same time; this is known as the "impenetrability of matter." The actual space occupied by the individual subatomic particles cannot be occupied by any other matter. The impenetrability of matter may, at first glance, seem invalid when a cup of salt is poured into a cup of water–the result is considerably less than two cups of salt water. However, matter has an additional general property called "porosity" which explains this apparent loss of volume: The water simply occupies space between particles of salt. Porosity is present in all material–but to an extremely wide range of degree. Generally, gases are extremely porous, liquids only slightly so; solids vary over a wide range, from the sponge to the steel ball.

INERTIA.–Every object tends to maintain a uniform state of motion. A body at rest never starts to move by itself; a body in motion will maintain its speed and direction unless it is

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caused to change. In order to cause a body to deviate from its condition of uniform motion, a push or a pull must be exerted on it. This requirement is due to that general property of all matter known as INERTIA.

The greater the tendency of a body to maintain uniform motion, the greater its inertia. The quantitative measure of inertia is the MASS of the body.

ACCELERATION.–Any change in the state of motion of a body is known as acceleration, and the cause which produces it is called an accelerating force. Acceleration is the rate of change in the motion of a body, and may represent either an increase or a decrease in speed and/or a change in direction of motion.

The amount of acceleration is stated as the change of velocity divided by the time required to make the change. For example, if a car traveling 15 mph increases its speed to 45 mph in 4 seconds, the 30 mph increase divided by 4 seconds gives 7.5 miles per hour per second as its acceleration. By converting the 30 mph to 44 feet per second, the acceleration could be expressed as 11 feet per second per second, or as 11 ft/sec^2.

FORCE.–Force is the action on a body which tends to change the state of motion of the body acted upon. A force may tend to move a body at rest; it may tend to increase or decrease the speed of a moving body; or it may tend to change the body's direction of motion. The application of a force to a body does not necessarily result in a change in the state of motion; it may only TEND to cause such a change.

A force is any push or pull which acts on a body. Water in a can exerts a force on the sides and bottom of the can. A tug exerts a push or a pull (force) on a barge. A man leaning against a bulkhead exerts a force on the bulkhead.

In the above examples, a physical object is exerting the force and is in direct contact with the body upon which the force is being exerted. Forces of this type are called contact forces. There are other forces which act through empty space without contact–in some cases without even seeming to have any mass associated with them. The force of gravity exerted on a body by the earth–known as the weight of the body–is an example of a force that acts on a body through empty space and without contact. Such a force is known as an action-at-a-distance force. Electric and magnetic forces are other examples of these action-at-a-distance forces. The space through which these action-at-a-distance forces are effective is called a force field.

Force is a VECTOR quantity; that is, it has both direction and magnitude. A force is completely described when its magnitude, direction, and point of application are given. In a force vector diagram, the starting point of the line represents the point of application of the force.

Any given body, at any given time, is subjected to many forces. In many cases, all these forces may be combined into a single RESULTANT force, which may then be used to determine the total effect on the body.

Each body of matter in the universe attracts every other body with a force which is proportional to the mass of the bodies and inverse to the square of the distance between them. This force is called the UNIVERSAL FORCE OF GRAVITATIONAL ATTRACTION. Since every body exerts this force on every other body, when considering the forces acting on a single body, it is an almost universal practice to resolve all gravitational forces into a single resultant. At or near the surface of the earth, this becomes a fairly simple process–due to its extremely large mass, the earth exerts such a large gravitational attraction that it is entirely practical to ignore all other such attractions and merely use the earth's gravitational attraction as the resultant.

Although gravitational attraction is exerted by each body on the other, in those cases where there is a great difference in the mass of two bodies, it is usually more convenient to consider the force as being exerted by the larger mass on the smaller mass. Thus, it is commonly stated that the earth exerts a gravitational force of attraction on a body. The gravitational attraction exerted by the earth on a body is called GRAVITY.

The gravitational force exerted by the earth on a body is called the WEIGHT of that body, and is expressed in force units. In the English system, force is expressed in pounds. If a body is attracted by a gravitational force of 160 pounds, the body is said to weigh 160 pounds. The

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gravitational force between two bodies decreases as the distance between them increases; therefore, a body weighs less a mile above the surface of the ocean than it weighs at sea level; it weighs more a mile below sea level.

Density and Specific Gravity

The DENSITY of a substance is its weight per unit volume. A cubic foot of water weighs 62.4 pounds; the density of water is 62.4 pounds per cubic foot. (In the metric system the density of water is 1 gram per cubic centimeter.)

The SPECIFIC GRAVITY (S.G.) of a substance is the ratio of the density of the substance to the density of water–

$$S.G. = \frac{\text{weight of substance}}{\text{weight of equal volume of water}}$$

Specific gravity is not expressed in units but as a pure number. For example, if a substance has a specific gravity of 4, 1 cubic foot of the substance weighs 4 times as much as a cubic foot of water–62.4 times 4 or 249.6 pounds. In metric units, 1 cubic centimeter of a substance with a specific gravity of 4 weighs 1 times 4 or 4 grams. (Note that in the metric system of units, the specific gravity of a substance has the same numerical value as its density.)

Specific gravity and density are independent of the size of the sample under consideration, and depend only upon the substance of which the sample is made. See table 4-4 for values of specific gravity for various substances.

The Aviation Electrician frequently works with equipment and systems in which the principles of density and specific gravity are involved. For instance, the state of charge of the lead acid battery may be determined by measuring the specific gravity of the electrolyte. If the specific gravity of the electrolyte is between 1.24 and 1.3 times the specific gravity of water, then the battery is normally considered to be charged.

Density and pressure must be considered when discussing altimetry and airspeed. Although very light, air has weight and is affected by gravity. By its weight, air exerts pressure on everything it touches. Since air is a gas, its pressure is exerted in all directions. Air pressure at a given altitude is determined by the weight of the air pressing down from above.

Table 4-4. --Values of specific gravity

Substance	Specific gravity
Platinum	21.3
Gold	19.3
Mercury	13.6
Lead	11.3
Silver	10.5
Copper	8.9
Brass	8.6
Iron	7.8
Steel	7.8
Aluminum	2.7
Sulphuric acid	1.83
Water	1.00
Ice	0.92
Ethyl alcohol	0.81
JP-4 jet fuel	0.75

The weight and compression of the atmosphere cause the molecules to be closer together and more numerous per unit volume at the bottom of the atmosphere, or where it rests upon the earth's surface. This means that the air at the bottom of the atmosphere is more dense than it is at higher altitudes. Air pressure at sea level on an average day will support a column of mercury 29.92 inches high as shown by the mercurial barometer in figure 4-9.

By definition, atmospheric pressure is a force per unit area, and force is equal to mass multiplied by acceleration. There is a change of pressure whenever either the mass of the atmosphere or the acceleration of the molecules within the atmosphere are changed. Although altitude exerts the dominant control, temperature and moisture alter pressure at any given altitude. Figure 4-10 shows the standard pressure and temperature at given altitudes.

Conditions are, however, very seldom "standard" for either temperature or pressure, which makes it necessary to make corrections in order to find density altitude or true airspeed. Let us consider an airfield that is under the influence of a low-pressure climatic condition where the

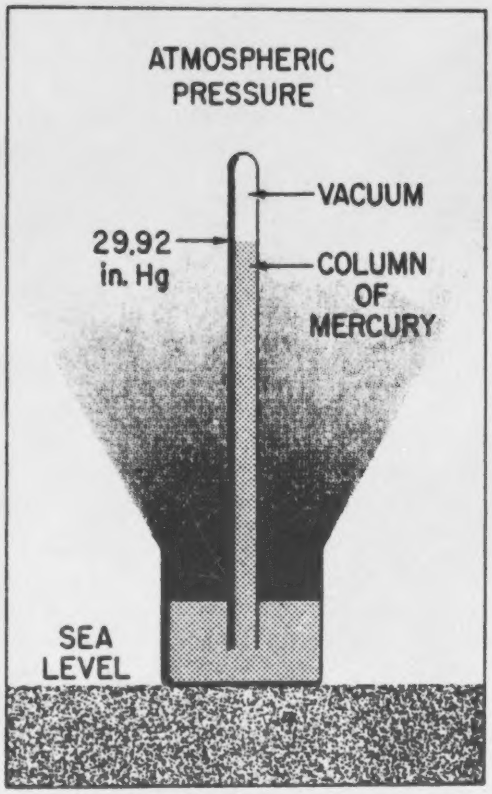

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Figure 4-9.—Mercurial barometer.

temperature is very hot. Together, these two conditions may reduce the density of the air to such an extent that the performance of an aircraft engine is affected and takeoff capability is marginal, especially for a helicopter. The density of air also directly affects resistance to the movement of an aircraft through the air, and thus the true airspeed of the aircraft.

Pressure and Total Force

Pressure and force, while closely related topics, are not the same thing. A weight of 10 pounds resting on a table exerts a force of 10 pounds. However, the shape of the weight must be taken into consideration to determine the effect of the weight. If the weight consists of a thin sheet of steel resting on a flat surface, the effect would be quite different if the same sheet of steel were resting on a sharp corner.

Pressure is concerned with the distribution of a force with respect to the area over which that force is distributed. Pressure is defined as the force per unit of area, or $P = F/A$. A flat pan of water with a bottom area of 24 square inches and a total weight of 72 pounds exerts a total force of 72 pounds, or a pressure of 72/24 or 3 pounds per square inch, on the flat table. If the pan is balanced on a block with a surface area of 1 square inch, the pressure is 72/1 or 72 pounds per square inch. An aluminum pan with a thin bottom is suitable for use on a flat surface, but may be damaged if placed on the small block.

This concept explains why a sharp knife cuts with less resistance than a dull one. The smaller area of the sharp edge concentrates the applied force (increases the pressure) and penetrates with greater ease. For hydraulic application, the relationship between pressure and force is the basic principle of operation. In enclosed liquids under pressure, the applied pressure is transmitted equally to every point on the surfaces of the enclosing container, and therefore the force on a given surface is dependent on the area.

MECHANICS

Mechanics is that branch of physics which deals primarily with the ideas of force, mass, and motion and is usually considered the fundamental branch of physics. Many of its principles and ideas may be seen, measured, and tested. Since all other branches of physics are also concerned (to some extent at least) with force, mass, and motion, a thorough understanding of this section will aid in the understanding of later sections of this chapter.

FORCE, MASS AND MOTION

Each particle in a body is acted upon by gravitational force. However, in every body there is one point at which a single force, equal

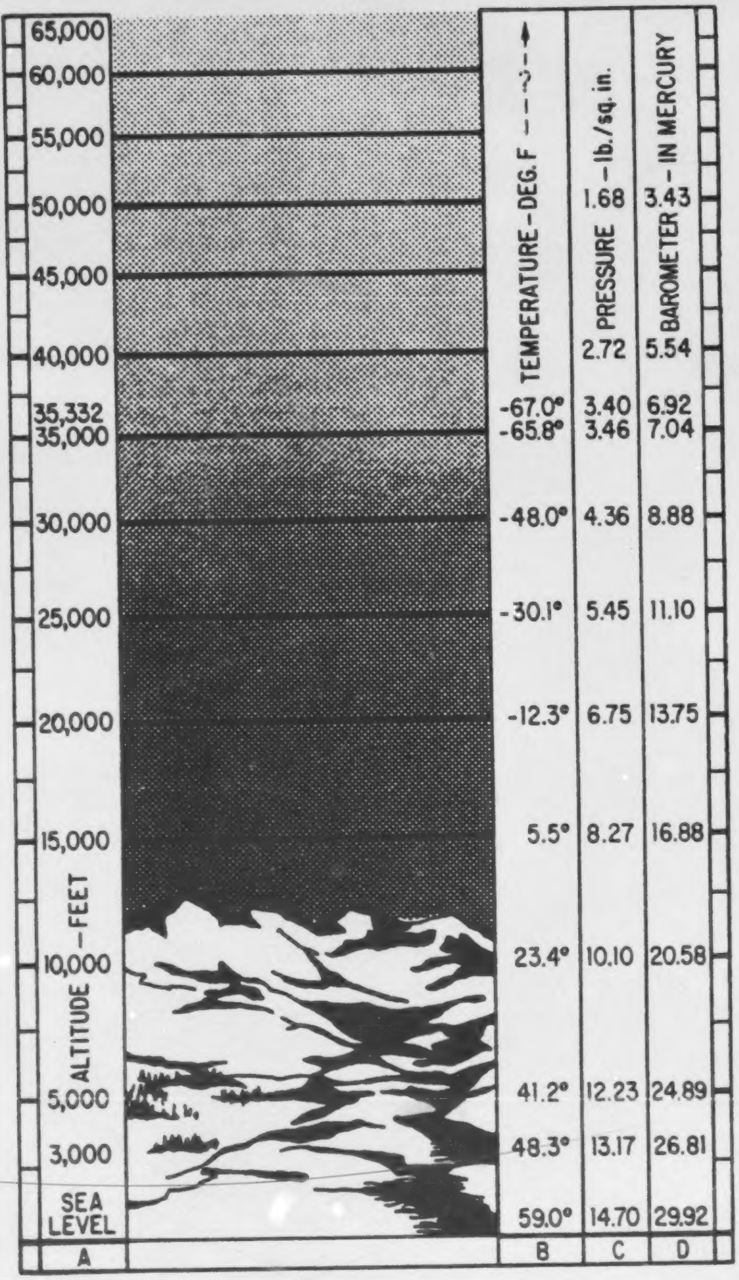

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Figure 4-10.—The standard atmosphere.

to the gravitational force and directed upward, would sustain the body in a condition of rest. This point is known as the CENTER OF GRAVITY, and represents the point at which the entire mass of the body appears to be concentrated. The gravitational effect is measured from the center of gravity. In symmetrical objects of uniform mass, this is the geometrical center. In the case of the earth, the center of gravity is near the center of the earth.

When considering the motion of a body, it is usually convenient to describe the path followed by the center of gravity. The natural tendency of a moving body is to move in a manner so that the center of gravity travels in a straight line. Movement of this type is called LINEAR motion.

Some moving bodies, however, do not move in a straight line but describe an arc or a circular path. Circular motion falls into two general classes–rotation and revolution.

Since objects come in many different shapes, in order to discuss rotary and revolutionary motion it becomes necessary to consider the location of the center of gravity with respect to the body. Refer to figure 4-11 for the following discussion.

In (A), the center of gravity of a ball coincides with the physical center of the ball. However, in the flat washer (B), the center of gravity does not coincide with any part of the object, but is located at the center of the hollow space inside the ring. In irregularly shaped bodies, the center of gravity may be difficult to locate exactly.

If the body is completely free to rotate, the center of rotation coincides with the center of gravity. On the other hand, the body may be restricted in such a manner that rotation is about some point other than the center of gravity. In this event, the center of gravity revolves around the center of rotation. These conditions are illustrated in figure 4-12.

In general usage, the gyro roter (A) is said to ROTATE about its axis, and the ball (B) is said to REVOLVE about a point at the center of its path.

Masses in Motion

MOTION may be defined as the "act or process of changing place or position." The "state of motion" refers to the amount and the type of motion possessed by a body at some definite instant (or during some interval) of time. A body at rest is not changing in place or position; it is said to have zero motion, or to be motionless.

The natural tendency of any body at rest is to remain at rest. A moving body tends to continue

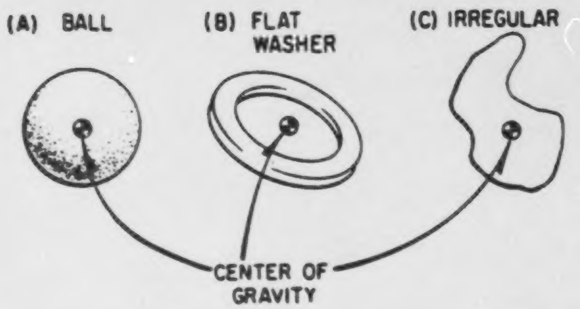


Figure 4-11.—Center of gravity in various bodies.

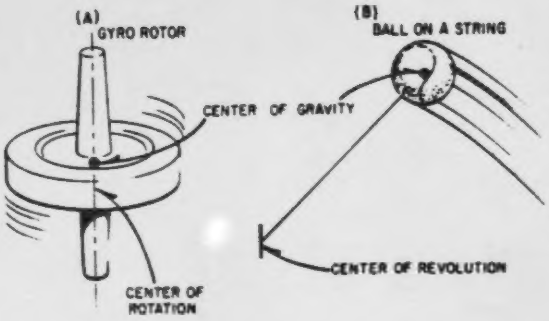


Figure 4-12.—Center of gravity and center of rotation.

moving in a straight line with no change in speed or direction, and a body which obeys this natural tendency is said to be in uniform motion.

Any change in the speed or direction of motion of a body is known as acceleration and requires the application of some force. Acceleration of a body is directly proportional to the force causing that acceleration; acceleration depends also upon the mass of the body acted upon. The greater mass of a lead ball makes it harder to move than a wood ball of the same diameter. The wood ball moves farther with the same push.

These observations point to a connection between force, mass, and acceleration, and indicate that the acceleration of a body is directly proportional to the force exerted on that body and inversely proportional to the mass of that body. In mathematical form, this relationship may be expressed as

$$a = \frac{F}{m}$$

or, as it is more commonly stated: Force is equal to the product of the mass and acceleration ($F = ma$).

Acceleration Due to Gravity

The small letter g used in formulas for solving for weight when mass is known ($W = mg$), represents the acceleration of a body in free fall, neglecting any friction. This can happen only in a vacuum. At sea level near the Equator, g has the approximate value of 32 ft/sec^2. Transposing the formula $W = mg$ to solve for m, the absolute units of mass of a body may be determined when its weight is known. Thus, when Newton's Second Law of Motion–force = mass times acceleration–is used to find the force necessary to give a one-ton weight an acceleration of 8 ft/sec^2, if $\frac{W}{g}$ is substituted for mass, then force $= \frac{2{,}000 \text{ lb}}{32 \text{ ft/sec}^2} \times 8 \text{ ft/sec}^2 = 500$ pounds.

The slug is a mass which would be accelerated 1 ft/sec^2 by a force of 1 pound. Since any mass falling freely under the pull of gravity has an acceleration of 32 ft/sec^2, this acceleration imparted to 1 slug could only be caused by a force of 32 pounds. In other words, a slug of mass weighs 32 pounds.

Example: A wagon weighing 160 pounds (5 slugs) stands at rest on a level surface. Neglecting friction, what acceleration will be given by a force of 20 pounds?

$$a = \frac{F}{m} = \frac{20 \text{ lb}}{5 \text{ slugs}} = 4 \text{ ft/sec}^2$$

The advantage of using absolute units for mass is more apparent when considering bodies in motion far removed from the earth where the pull of gravity is greatly reduced. The 5-slug wagon would experience the same acceleration when acted on by the given force, even though its weight be greatly reduced.

In the metric system the newton is the force which causes a mass of 1 kg to be accelerated 1 m/sec^2. Since $g = 9.8$ m/sec^2, a 1-kg mass exerts a force of 9.8 newtons due to gravity. A newton is equal to 0.224 lb.

The dyne is the force which causes a mass of 1 gm to be accelerated 1 cm/sec^2, so a 1-gm mass exerts a force of 980 dynes due to gravity.

If the accelerating force is applied to the center of gravity in such a manner as to accelerate the body with no rotation, it is called a TRANSLATIONAL force. A force applied in such a manner as to cause the body to rotate about a point is called a TORQUE force.

Laws of Motion

Among the most important discoveries in theoretical physics are the three fundamental laws of motion attributed to Newton. Although some of these laws have been used in explanations of various topics earlier in this chapter, they are restated and consolidated at this point to clarify and summarize much of the discussion regarding mechanical physics. This restatement and consolidation are also used to introduce additional aspects involving the application of basic mechanical principles.

1. Every body tends to maintain a state of uniform motion unless a force is applied to change the speed or direction of motion.
2. The acceleration of a body is directly proportional to the magnitude of the applied force and inversely proportional to the mass of the body; acceleration is in the direction of the applied force.
3. For every force applied to a body, the body exerts an equal force in the opposite direction.

Momentum

Every moving body tends to maintain uniform motion. Quantitative measurement of this tendency is proportional to the mass of the body, and also to its velocity. (Momentum = mass X velocity.) This explains why heavy objects in motion at a given speed are harder to stop than lighter objects, and also why it is easier to stop a given body moving at low speed than it is to stop the same body moving at high speed.

WORK, POWER, AND ENERGY

As defined earlier, energy is the capacity for doing work. In mechanical physics, WORK involves the idea of a mass in motion, and is usually regarded as the product of the applied force and the distance through which the mass is moved (work = force X distance). Thus, if a man raises a weight of 100 pounds to a height of 10 feet he accomplishes 1,000 foot-pounds of work. The amount of work accomplished is the same regardless of the time involved. However, the RATE of doing the work may vary greatly.

The rate of doing work (called POWER) is defined as the work accomplished per unit of time (power = work/time). In the example cited above, if the work is accomplished in 10 seconds, power is being expended at the rate of 100 foot-pounds per second; if it takes 5 minutes (300 seconds), the rate is approximately 3.3 foot-pounds per second.

In the English system of measurements, the unit of mechanical power is called the HORSEPOWER and is the equivalent of 33,000 foot-pounds per minute, or 550 foot-pounds per second. Since energy is readily convertible from one form to another, the work and power measurements based on the conversion of energy must also be readily convertible. As an example, the electrical unit of power is the watt. Electrical energy may be converted into mechanical energy; therefore, electrical power must be convertible into mechanical power. One horsepower is the mechanical equivalent of 746 watts of electrical power, and is capable of doing the same amount of work in the same time.

The accomplishment of work always involves a change in the type of energy, but does not change the total quantity of energy. Thus, energy applied to an object may produce work, changing the composition of the energy possessed by the object.

Potential Energy

A body is said to have potential energy if by virtue of its position or its state it is able to do work. A wound clock spring and a cylinder of compressed gas both possess potential energy since they can do work in returning to their uncompressed condition. Also, a weight raised above the earth has potential energy since it can do work in returning to the ground. Thus, potential energy results when work has been done against a restoring force. The water in a reservoir above a hydroelectric plant has potential energy regardless of whether the water was placed there by work applied via a pump or by the work done by the sun to lift it from the sea and place it in the reservoir in the form of rain.

Kinetic Energy

The ability of a body to do work by virtue of its MOTION is called its kinetic energy. A rotating wheel on a machine has kinetic energy of rotation. A car moving along the highway has kinetic energy of translation.

For a given mass m, moving in a straight line with a velocity v, the kinetic energy is determined by

$$\text{Kinetic energy} = \tfrac{1}{2}mv^2 \begin{cases} \text{in ergs when} \begin{cases} \text{m is in grams} \\ \text{v is in cm per sec} \end{cases} \\ \text{in ft-lbs when} \begin{cases} \text{m is in slugs} \\ \text{v is in ft per sec} \end{cases} \end{cases}$$

Example: The kinetic energy of a 3,200-lb car which is traveling at 30 miles per hour can be found by expressing the 3,200 lb as 100 slugs and the 30 mph as 44 feet per second. Inserting these values into the formula gives kinetic energy = ½ X 100 X 44 X 44 = 96,800 foot-pounds of energy. This amount of kinetic energy is the result of 96,800 foot-pounds of work (plus that to overcome friction) having been applied to the car to get it traveling at the rate of 44 feet per second. This same amount of energy could do the work of lifting the 3,200 pounds vertically a distance of 30.25 feet, and so could have been potential energy if the car had been at rest on an incline and then allowed to coast to a point which is vertically 30.25 feet below its starting point (again neglecting friction).

Efficiency

Provided there is no change in the quantity of matter, energy is convertible with no gain or loss. However, the energy resulting from a given action may not be in the desired form—it may not even be usable in its resultant form. In all branches of physics, this concept is known as EFFICIENCY.

The energy expended is always greater than the energy recovered. An automobile in motion possesses a quantity of kinetic energy dependent on its mass and velocity. In order to stop the car, this energy must be converted into potential energy. When the car comes to rest, its potential energy is considerably less than the kinetic energy it possessed while in motion. The difference, or the "energy lost" is converted into heat by the brakes. The heat serves no useful purpose, so the recovered energy is less than the expended energy—the system is less than 100 percent efficient in converting kinetic to potential energy.

The term efficiency is normally used in connection with work and power considerations to denote the ratio of the input to the output work, power, or energy. It is always expressed as a decimal or as a percent less than unity.

Friction

In mechanical physics, the most common cause for the loss of efficiency is FRICTION. Whenever one object is slid or rolled over another, irregularities in the contacting surfaces interlock and cause an opposition to the force being exerted. Even rubbing two smooth pieces of ice together produces friction, although of a much smaller magnitude than in the case of two rough stones. Friction also exists in the contact of air with all exposed parts of an aircraft in flight.

When a nail is struck with a hammer, the energy of the hammer is transferred to the nail, and the nail is driven into a board. The depth of penetration depends on the momentum of the hammer, the size and shape of the nail, and the hardness of the wood. The larger or duller the nail and the harder the wood, the greater the friction, and therefore the lower the efficiency and less depth of penetration—but the greater the heating of the nail.

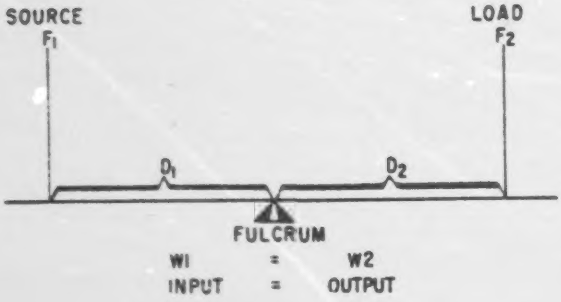
Friction is always present in moving machinery, and accounts in part for the fact that the useful work accomplished by the machine is never as great as the energy applied. Work accomplished in overcoming friction is usually not recoverable. Friction can be minimized by decreasing the number of contacting points, by making the contacting areas as small and as smooth as possible, by the use of bearings, or by the use of lubricants.

There are two kinds of friction—sliding and rolling, with rolling friction usually of lower magnitude. Therefore, most machines are constructed so that rolling friction is present rather than sliding friction. The ball bearing and the roller bearing are used to convert sliding friction to rolling friction. A third type, the common (or friction) bearing, utilizes lubricants applied to surfaces which have been made as smooth as possible. Many new types of machines utilize self-lubricating bearings to minimize friction and thus maximize efficiency.

Mechanical Advantage

The concept of mechanical advantage has proven to be one of the great discoveries of science. It permits an increase in force or distance and represents the basic principle involved in levers, block and tackle systems, screws, hydraulic mechanisms, and other work saving devices. However, in the true sense, these devices do not save work, they merely enable humans to accomplish tasks which might otherwise be beyond their capability. For example, a human would normally be considered incapable of lifting the rear end of a truck in order to change a tire; but with a jack, a block and tackle, or a lever, the job can be made comparatively easy.

Mechanical advantage is usually considered with respect to work. Work represents the application of a force through a distance in order to move an object through a distance. Thus, it may be seen that there are two forces involved, each with an appropriate distance. This is illustrated by the simple lever in figure 4-13.



AE.21

Figure 4-13.—Mechanical advantage.

Assuming perfect efficiency, the work input (F_1D_1) is equal to the work output (F_2D_2). Assuming equal distances D_1 and D_2, a force of 10 pounds must be applied at the source in order to counteract a weight of 10 pounds at the load. By moving the fulcrum nearer the load, less force is required to balance the same load. This is a mechanical advantage of force. If the force is applied in such a manner as to raise the load 1 foot, the source must be moved through a distance greater than 1 foot. Thus, mechanical advantage of force represents a mechanical disadvantage of distance. By moving the fulcrum nearer the source, these conditions are reversed.

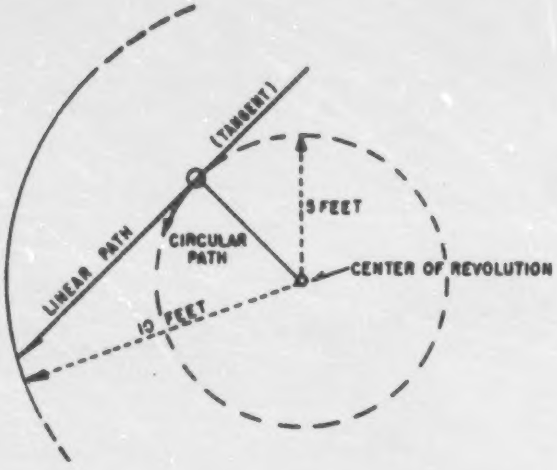
Since the input work equals the output work (assuming no losses), the mechanical advantage may be stated as a ratio of the force or of the distances. In actual situations, friction results in energy loss and decreased efficiency, thereby requiring an even greater input to accomplish the same work.

REVOLVING BODIES

Revolving bodies represent masses in motion; therefore, they possess all the characteristics (and obey all the laws) associated with moving bodies. In addition, since they possess a specific type of motion, they have special properties and factors which must be taken into consideration.

Revolving bodies travel in a constantly changing direction, so they must be constantly subjected to an accelerating force. Momentum tends to produce linear motion, but this is prevented by application of a force which restrains the object. This restraining force prevents the object from continuing in a straight line, and is known as CENTRIPETAL force. According to Newton's third law of motion, the centripetal force must be opposed by an equal force which tends to produce linear motion. This second force is known as CENTRIFUGAL force. The two forces, their relationships, and their effects are illustrated in figure 4-14.

The various forces involved in revolving bodies may be illustrated by use of a ball and string. A slip knot is tied in the center of a 10-foot length of twine so as to shorten the line to 5 feet; a rubber ball is attached to one end of the string. Holding the other end of the line,



AE.22

Figure 4-14.–Forces on revolving bodies.

whirl the ball slowly in a circle. Note that the ball exerts a force against the hand (through the string); and that in order to restrain the ball in its circular path, the hand must exert a force (through the string) on the ball. As the ball is revolved at higher speed, the forces increase, and the ball continues in a circular path. As the rotational velocity of the ball is gradually increased, note the increasing forces.

At some rotational speed, the forces involved become great enough to overcome inertial friction, and the knot slips. At this time, allow the velocity of the rotation to stabilize (stop increasing in rotational velocity, but not slowing down, either), so that the existing conditions may be analyzed. When the knot slips, the ball is temporarily unrestrained and is free to assume linear motion in the direction of travel at that instant (tangent to the circle at the instantaneous position). The ball travels in a straight line until the string reaches its full length; during this time, no force is exerted on or by the hand. As soon as all the slack is taken up, there is a sharp jerk–an accelerating force is exerted in order to change the direction of motion from its linear path into a circular rotation. The ball again assumes rotational motion, but with an increase in radius.

The ball does not make as many revolutions in the same time (rotational velocity is decreased), but it does maintain its former linear velocity. (The kinetic energy and the momentum of the ball have not changed.) Since the change in direction is less abrupt with a large radius than with a small one, less accelerating force is required, and the hand will feel less force. If the ball is then accelerated to the same rotational velocity as immediately prior to the slipping of the knot, the linear velocity of the ball becomes much greater than before; the centripetal and centrifugal forces are much greater, also.

In this example, it has been assumed that the hand is fixed at a point which represents the center of rotation. This assumption, while somewhat erroneous, does not affect the general conclusions. For practical purposes, the two forces are equal at all points along the string at any given time, and the magnitude of each force is equal at all points along the string.

In summarizing the conclusions reached by the above example and explanation, consider the following relationship:

$$\text{force} = \frac{\text{mass} \times \text{velocity}^2}{\text{radius}}$$

where velocity represents the linear velocity of the ball. This emphasizes that the centripetal and the centrifugal forces are equal in magnitude and opposite in direction. Each force is directly proportional to the mass of the body and inversely proportional to the radius of rotation. Each force is also proportional to the square of the velocity.

In revolving or rotating bodies, all particles of the matter which are not on the axis of rotation are subjected to the forces just described. The statement is true whether the motion is through a complete circle, or merely around a curve. An automobile tends to take curves on two wheels–the sharper the curve (smaller radius) or the higher the velocity, the greater the tendency to skid.

HEAT

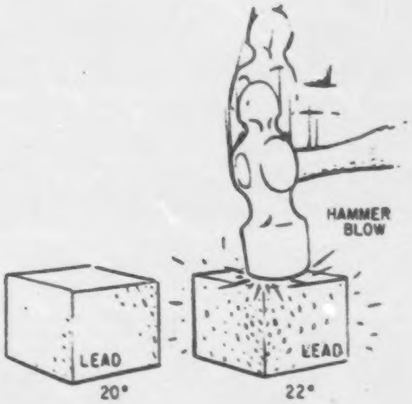
Heat represents a form of energy; therefore, it must be readily exchangeable with, or convertible into, other forms of energy. When a piece of lead is struck a sharp blow with a hammer, part of the kinetic energy of the hammer is converted into heat. (See fig. 4-15.) In the core of a transformer, electrical and magnetic energy are exchanged, but due to hysteresis and eddy currents, some of the energy is lost as heat. These are some examples of the unwanted conversions, but there are many instances when the production of heat is desirable. Many devices are used almost exclusively to produce heat.

Regardless of how or why it is produced, heat possesses certain characteristics which make it important to the AE. A knowledge of the nature and behavior of heat may prove helpful in understanding the operation of some types of avionics equipment, or in determining the cause of nonoperation or faulty operation of others.

NATURE OF HEAT

There are several theories regarding the nature of heat, none of which satisfactorily explain all the characteristics and properties exhibited by heat. The two theories most commonly included in discussions regarding the nature of heat are the kinetic theory and the radiant energy theory.

In the kinetic theory, it is assumed that the quantity of heat contained by a body is represented by the total kinetic energy possessed by the molecules of the body.



AE.5

Figure 4-15.—Generation of heat.

The radiation theory treats radio waves, heat, and light as the same general form of energy, differing primarily in frequency. Heat is considered as a form of electromagnetic energy involving a specific band of frequencies falling between the radio spectrum and light.

A common method used to produce heat energy is the burning process. Burning is a chemical process in which the fuel unites with oxygen, and a flame is usually produced. The amount of heat liberated per unit mass or per unit volume during complete burning is known as the heat of combustion of a substance. By experiment, scientists have found that each fuel produces a given amount of heat per unit quantity burned.

TRANSFER OF HEAT

There are three methods of heat transfer—conduction, convection, and radiation. In addition to these, a phenomenon called absorption is related to the radiation method.

Conduction

The metal handle of a hot pot may burn the hand; a plastic or wooden handle, however, remains relatively cool even though it is in direct contact with the pot. This phenomenon is due to a property of matter known as thermal conductivity. All materials conduct heat—some very readily, some to an almost negligible extent. When heat is applied to a body, the molecules at the point of application become violently agitated, strike the molecules next to them, and cause increased agitation. The process continues until the heat energy is distributed evenly throughout the material. Aluminum and copper are used for cooking pots because they conduct heat very readily to the food being cooked. Wood and plastic are used as handles because they are very poor conductors of heat. As a general rule metals are the best conductors of heat, although some metals are considerably better than others.

Figure 4-16 shows an example of the different rates of conduction of various metals. Four rods of different metals have several wax rings hanging on them. One flame is used to simultaneously heat one end of each rod. The rings drop off from the copper rod first, then from the aluminum rod, then from the nickle rod, and last from the iron rod. This example shows that among the four metals used, copper is the best conductor of heat and iron is the poorest.

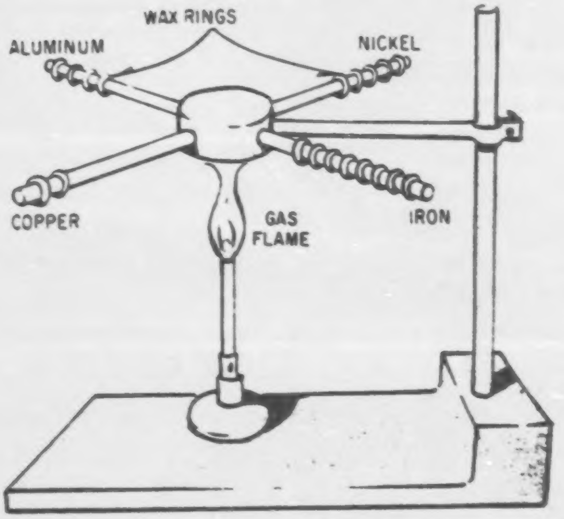
Among solids, there is an extreme range of thermal conductivity. In the original example, the metal handle transmits heat from the pot to the hand, with the possibility of burns. The wooden or plastic handle does not conduct heat very well, so the hand is given some protection. Materials that are extremely poor conductors are called "insulators" and are used to reduce heat transfer. Some examples are the wood handle of soldering irons, the finely spun glass or rock wool insulation in houses, or the asbestos tape or ribbon wrapping used on steam pipes.

Liquids are generally poorer conductors than metals. In figure 4-17, note that the ice in the bottom of the test tube has not yet melted, although the water at the top is boiling. Water is such a poor conductor that the rate of heating of the water at the top of the tube is not sufficient to cause rapid melting of the ice at the bottom.

Since thermal conduction is a process by which molecular energy is passed on by actual contact, gases are generally even poorer conductors than liquids because the molecules are farther apart and molecular contact is not so pronounced. A double-pane window with an airspace between the panes is a fair insulator.

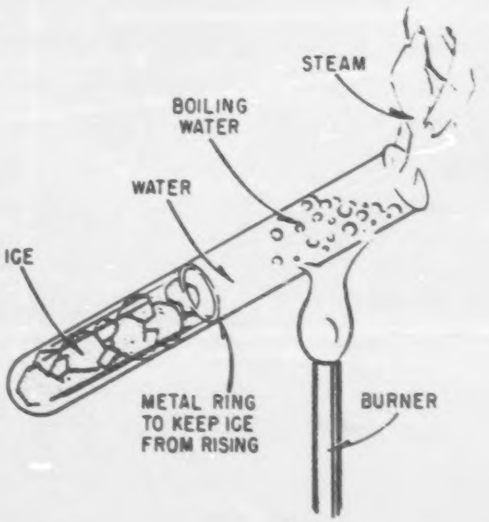
Convection

Convection is the process in which heat is transferred by movement of a hot fluid. For example, an electron tube gets hotter and hotter until the air surrounding it begins to move. The motion of the air is upward because heated air expands in volume and is forced upward by the denser cool air surrounding it. The upward motion of the heated air carries the heat away from the hot tube by convection. Transfer of heat by convection may be hastened by using a ventilating fan to move the air surrounding a hot object. The rate of cooling of a hot vacuum tube can also be increased by providing copper fins to



AE.6

Figure 4-16.—Various metals conduct heat at different rates.



AE.7

Figure 4-17.—Water is a poor conductor of heat.

conduct heat away from the hot tube. The fins provide large surfaces against which cool air can be blown.

A convection process may take place in a liquid as well as in a gas. One example is a transformer in an oil bath. The hot oil is less dense (has less weight per unit volume) and rises, while the cool oil falls, is heated, and rises in turn.

When the circulation of gas or liquid is not rapid enough to remove sufficient heat, fans or pumps may be used to accelerate the motion of the cooling material. In some installations, pumps are used to circulate water or oil to help cool large equipment. In airborne installations electric fans and blowers are used to aid convection.

Radiation

Conduction and convection cannot wholly account for some of the phenomena that are associated with heat transfer. For example, heating through convection cannot occur in front of an open fire because the air currents are moving toward the fire. It cannot occur through conduction because the conductivity of the air is very low, and the cooler currents of air moving toward the fire would more than overcome the transfer of heat outward. Therefore, heat must travel across space by some means other than conduction and convection.

The existence of another process of heat transfer is still more evident when the heat from the sun is considered. Since conduction and convection take place only through molecular contact within some medium, heat from the sun must reach the earth by some other method. (Outer space is an almost perfect vacuum.) Radiation is the name given to this third method by which heat travels from one place to another.

The term radiation refers to the continual emission of energy from the surface of all bodies. This energy is known as radiant energy. It is in the form of electromagnetic waves and is identical in nature with light waves, radio waves, and X-rays, except for a difference in frequency. Sunlight is a form of radiant heat energy which travels great distances through cold, empty space to reach the earth. These electromagnetic heat waves are absorbed when they come in contact with nontransparent bodies. The net result is that the motion of the molecules in the body is increased, as indicated by an increase in the temperature of the body.

The differences in conduction, convection, and radiation are as follows:

1. Although conduction and convection are extremely slow, radiation takes place with the speed of light. This fact is evident at the time of an eclipse of the sun when the shutting off of the heat from the sun takes place at the same time as the shutting off of the light.
2. Radiant heat may pass through a medium without heating it. For example, the plants inside a greenhouse may be much warmer than the glass through which the sun's rays pass.
3. Although conducted or convected heat may travel in roundabout routes, radiant heat always travels in a straight line. Thus, radiant heat can be stopped with a screen placed between the source of heat and the body to be protected.

Absorption

The sun, a fire, and an electric light bulb all radiate energy, but a body need not glow to give off heat. A kettle of hot water or a hot soldering iron radiates heat. If the surface is polished or light in color, less heat is radiated. Bodies which do not reflect are good radiators and good absorbers, and bodies that reflect are poor radiators and poor absorbers. This is the reason white clothing is worn in the summer. A practical example of the control of heat is the Thermos bottle. The flask itself is made of two walls of "silvered" glass with a vacuum between them. The vacuum prevents the loss of heat by conduction and convection and the "silver" coating reduces the loss of heat by radiation.

The silver-colored paint on the "radiators" in heating systems is used only for decoration and decreases the efficiency of heat transfer. The most effective color for heat transfer is dull black; dull black is the ideal absorber and also the best radiator.

THERMAL EXPANSION

Nearly all substances expand or increase in size when their temperature increases. Railroad tracks are laid with small gaps between the sections to prevent buckling when the temperature increases in summer. Concrete pavement has strips of soft material inserted at intervals to prevent buckling when the sun heats the roadway. A steel building or bridge is put together with red-hot rivets so that when the rivets cool they will shrink and the separate pieces will be pulled together very tightly. A fuel tank that has been filled in the cool of early morning will overflow in the heat of the afternoon.

As a substance is expanded by heat, the weight per unit volume decreases. This is because the weight of the substance remains the same while the volume is increased by the application of heat. Thus the density decreases with an increase in temperature.

Experiments show that for a given change in temperature, the change in length or volume is different for each substance. For example, a given change in temperature causes copper to expand nearly twice as much as glass of the same size and shape. For this reason, the connecting wires into an electronic tube cannot be made of copper but must be made of a metal that expands at the same rate as glass. If the metal did not expand at the same rate as the glass, the vacuum in the tube would be broken by air leaking past the wires in the glass stem. If the metal expanded at a greater rate than the glass, the glass would be broken. Through research, a material (Kovar) was developed that adheres to the glass and the metal pins of the tube, has a certain degree of elasticity, and the same expansion coefficient as glass.

The amount that a unit length of any substance expands for a 1° rise in temperature is known as the coefficient of linear expansion for that substance.

Coefficients of Expansion

To estimate the expansion of any object, such as a steel rail, it is necessary to know three things about it–its length, the rise in temperature to which it is subjected, and its rate of coefficient of expansion. The amount of expansion is expressed by the following equation:

expansion = coefficient × length × rise in temperature

or

$$e = kl(t_2 - t_1)$$

In this equation, the letter k represents the coefficient of expansion for the particular substance. In some instances, the Greek letter α (alpha) is used to indicate the coefficient of linear expansion.

PROBLEM: If a steel rod measures exactly 9 feet at 21° C, what is its length at 55° C? (The coefficient of linear expansion for steel is 11×10^{-6}.) If the equation $e = kl(t_2 - t_1)$ is used, then

$$e = (11 \times 10^{-6}) \times 9(55 - 21)$$

$$e = 0.000011 \times 9 \times 34$$

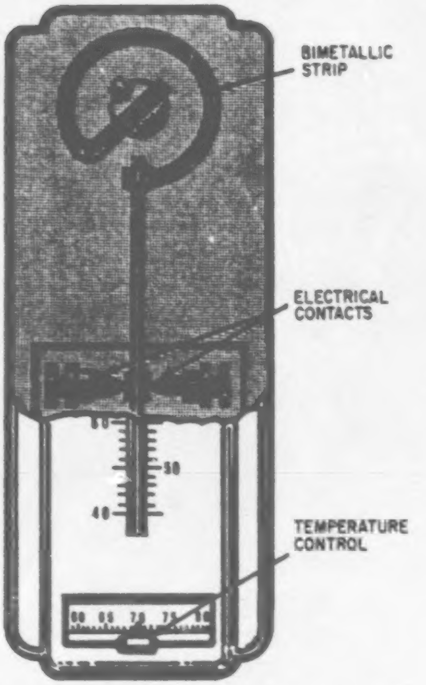
$$e = 0.003366$$

This amount, when added to the original length of the rod, make's the rod 9.003366 feet long. Since the temperature has increased, the rod is longer by the amount of e. If the temperature had been lowered, the rod would have become shorter by a corresponding amount.

The increase in the length of the rod is relatively small; but if the rod were placed where it could not expand freely, there would be a tremendous force exerted due to thermal expansion. Thus, thermal expansion must be taken into consideration when designing ships, buildings, and all forms of machinery.

Table 4-5 is a list of the coefficients of approximate linear expansion of some substances per degree C.

A practical application for the differences in the coefficients of linear expansion is the thermostat. This instrument comprises two strips of dissimilar metal fastened together. When the temperature changes, a bending takes place due to unequal expansion of the metals. (See fig. 4-5.) Thermostats are used in overload relays for motors, in temperature sensitive switches, and in electric ovens. (See fig. 4-18.)



AE.18

Figure 4-18.—Thermostat.

Table 4-5—Expansion coefficients

Substance	Coefficient of linear expansion
Aluminum	24×10^{-6}
Brass	19×10^{-6}
Copper	17×10^{-6}
Glass	4 to 9×10^{-6}
Kovar	4 to 9×10^{-6}
Lead	28×10^{-6}
Iron, steel	11×10^{-6}
Quartz	0.4×10^{-6}
Zinc	26×10^{-6}

The coefficient of surface or area expansion is approximately twice the coefficient of linear expansion. The coefficient of volume expansion is approximately three times the coefficient of linear expansion. It is interesting to note that in a plate containing a hole, the area of the hole expands at the same rate as the surrounding material. In the case of a volume enclosed by a thin solid wall, the volume expands at the same rate as would a solid body of the material of which the walls are made.

MEASUREMENT OF HEAT

A unit of heat must be defined as the heat necessary to produce some agreed-on standard of change. There are three such units in common use.

1. One British thermal unit (Btu) is the quantity of heat necessary to raise the temperature of 1 pound of water 1° F.
2. One gram-calorie (small calorie) is the quantity of heat necessary to raise 1 gram of water 1° C.
3. One kilogram-calorie (large calorie) is the quantity of heat necessary to raise 1 kilogram of water 1° C. (One kilogram-calorie equals 1,000 gram calories.)

The gram-calorie or small calorie is much more widely used than the kilogram-calorie or large calorie. The large calorie is used in relation to food energy and for measuring comparatively large amounts of heat. Throughout this discussion, unless otherwise stated, the term calorie means gram-calorie. For purposes of conversion, one Btu equals 252 gram-calories or 0.252 kilogram-calories.

The terms "quantity of heat" and "temperature" are frequently misused. The distinction between them should be understood clearly. For example, suppose that two identical pans, containing different amounts of water of the same temperature, are placed over identical gas burner flames for the same length of time. At the end of that time, the smaller amount of water will have reached a higher temperature. Equal amounts of heat have been supplied, but the increases in temperatures are not equal. As another example, suppose that the water in both pans is at the same temperature, say 80° F, and both are to be heated to the boiling point. It is obvious that more heat must be supplied to the larger amount of water. The temperature rises are the same for both pans, but the quantities of heat necessary are different.

Mechanical Equivalent

Mechanical energy is usually expressed in ergs, joules, or foot-pounds. Energy in the form of heat is expressed in calories or in Btu. In a precise experiment in which electric energy is converted into heat in a resistance wire immersed in water, the results show that 4.186 joules equals 1 gram-calorie, or that 778 foot-pounds equals 1 Btu. The following equation is used when converting from the English system to the metric system:

$$1 \text{ Btu} = 252 \text{ calories}$$

Specific Heat

One important way in which substances differ from one another is that they require different quantities of heat to produce the same temperature change in a given mass of substance. The thermal capacity of a substance is the calories of heat needed, per gram mass, to increase the temperature 1° C. The specific heat of a substance is the ratio of its thermal capacity to the thermal capacity of water at 15° C. Specific heat is expressed as a number which, because it is a ratio, has no units and applies to both the English and the metric systems.

Water has a high thermal heat capacity. Large bodies of water on the earth keep the air and the surface of the earth at a fairly constant temperature. A great quantity of heat gain or loss is required to change the temperature of a large lake or river. Therefore, when the temperature of the air falls below that of such bodies of water, they give off large quantities of heat to the air. This process keeps the atmospheric temperature at the surface of the earth from changing very rapidly.

Table 4-6 gives the specific heats of several common substances listed in descending order. To find the heat required to raise the temperature of a substance, multiply its mass by the rise in temperature times its specific heat.

Example: It takes 1,000 Btu to raise the temperature of 100 pounds of water 10° F, but only 31 Btu to raise 100 pounds of lead 10° F.

Table 4-6.–Specific heats of some common substances

Hydrogen (at constant pressure)	3.409
Water at 4° C	1.0049
Water at 15° C	1.0000
Water at 30° C	0.9971
Ice at 0° C	0.502
Steam at 100° C	0.421
Air (at constant pressure)	0.237
Aluminum	0.217
Glass	0.160
Iron	0.114
Copper	0.093
Brass, zinc	0.092
Silver	0.057
Tin	0.056
Mercury	0.033
Gold, lead	0.031

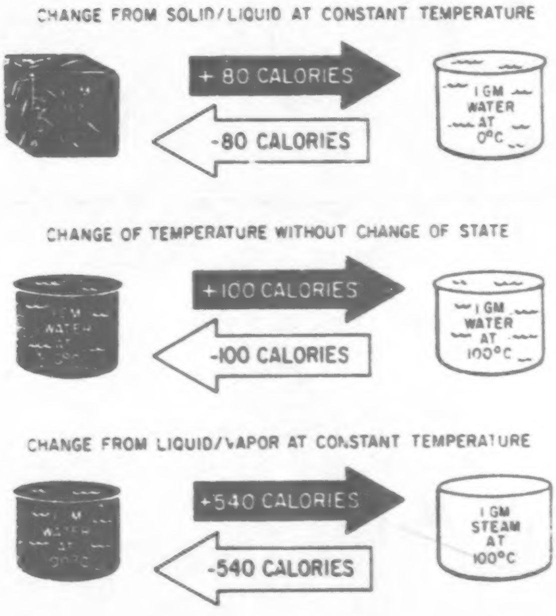
CHANGE OF STATE

A thermometer placed in melting snow behaves in a strange manner. The temperature of the snow rises slowly until it reaches 0° C. Provided that the mixture is stirred constantly, it remains at that point until all the snow has changed to water; when all the snow has melted, the temperature again begins to rise. A definite amount of heat is required to change the snow to water at the SAME temperature. This heat is required to change the water from crystal form to liquid form.

Heat of Fusion

Eighty gram-calories of heat are required to change 1 gram of ice at 0° C to water at 0° C, and this is called the HEAT OF FUSION of water. The heat used while the ice is melting represents the work done to produce the change of state. Since 80 calories are required to change a gram of ice to water at 0° C, when a gram of water is frozen it gives up 80 calories. This is illustrated in figure 4-19.

Many substances behave very much like water. At a given pressure, they have a definite heat of fusion and an exact melting point. There are many materials, however, which do not change from a liquid to a solid state at one temperature. Molasses, for example, gets thicker and thicker as the temperature decreases but there is no exact temperature at which the change of state occurs. Wax, celluloid, and glass are other substances which do not change from a liquid to a solid state at any particular temperature. In fact, measurements of the glass thickness at the bottom of windows in ancient cathedrals tend to indicate that the glass is still flowing at an extremely slow rate. Most types of solder used in avionics maintenance also tend to become mushy before melting.



AE.12

Figure 4-19.—Thermal history of 1 gram of water.

Heat of Vaporization

Damp clothing dries more rapidly under a hot flatiron than under a cold one. A pool of water evaporates more rapidly in the sun than in the shade. Thus, it may be concluded that heat has something to do with evaporation. The process of changing a liquid to a vapor is similar to that which occurs when a solid melts.

If a given quantity of water is heated until it evaporates—that is, changes to a gas (vapor)—a much greater amount of heat is used than that which is necessary to raise the same amount of water from the freezing point to the boiling point. For example, 540 calories are required to change 1 gram of water to vapor at a temperature of 100° C, while only 100 calories were required to change the temperature from the freezing point to the boiling point. The amount of heat necessary to change boiling water to vapor is called the HEAT OF VAPORIZATION of water. Over five times as much heat is required to change a given amount of water to vapor than to raise the same amount of water from the freezing to the boiling point.

BOILING.—When water is heated, some vapor forms before the boiling point is reached. The change from water to vapor occurs as follows: As the water molecules take up more and more energy from the heating source, their kinetic energy increases. The motion resulting from the high kinetic energy of the water molecules causes a pressure which is called the vapor pressure. As the velocity of the molecules increases, the vapor pressure increases. At sea level, atmospheric pressure is normally 29.92 inches of mercury. The boiling point of a liquid is that temperature at which the vapor pressure equals the external or atmospheric pressure. At normal atmospheric pressure at sea level, the boiling point of water is 100° C.

While the water is below the boiling point, a number of molecules acquire enough kinetic energy to break away from the liquid state into a vapor. For this reason some evaporation slowly takes place below the boiling point. At the boiling point, large numbers of molecules have enough energy to change from liquid to vapor, and evaporation takes place much more rapidly.

If the molecules of water are changing to water vapor in an open space, the air currents carry them away quickly. In a closed container, they rapidly become crowded and some of them return to liquid as a result of collisions. When as many molecules are returning to the liquid state as are leaving it, the vapor is said to be saturated. Experiments have shown that saturated vapor in a closed container exerts a pressure and has a given density at every temperature.

CHAPTER 5

AIRCRAFT STORAGE BATTERIES

The function of the aircraft storage battery is to provide an emergency source of electrical power for operating the electrical systems of an aircraft. The battery also functions in such a manner that it reduces the commutator ripple produced on aircraft equipped with d-c generators. During normal aircraft operation, either the a-c generator and the transformer-rectifier combination, or the d-c generator supplies the primary source of electrical energy and maintains the battery in a charged state. The battery supplies power to the aircraft only when the generating systems are unable to supply sufficient power, either because of a faulty generator system or due to the slow speed of the generator drive.

Since the battery is the emergency power source for the aircraft, extreme care must be taken to see that every precaution is taken to maintain the battery in perfect condition. Therefore, the battery should never be used for starting engines or servicing equipment if another source of power is available. Such unnecessary usage tends to shorten the life of the battery and keeps it in poor condition to meet emergency operation requirements. During periods when the engines are idling or being started, the electrical load should be kept at a minimum. The service life of the aircraft battery depends a great deal upon the frequency and quality of care it is given. Batteries that are abused or that receive careless treatment and servicing generally have their service life ended prematurely.

The most common aircraft battery in use today is the lead-acid type. However, two recent types, which are known as the nickel-cadmium and the silver-zinc batteries, are being used in some aircraft. The basic principles of all three types of batteries are covered in detail in the chapter titled "Batteries" in Basic Electricity, NavTra 10086-B.

As an AE, you will be required to maintain aircraft batteries in either of two maintenance situations:

1. At an organizational aircraft maintenance activity where testing, installation, and removal of batteries, and maintenance of battery-associated components is accomplished.
2. At an intermediate aircraft maintenance activity where batteries are received, tested, repaired, and reissued or disposed of as necessary.

ORGANIZATIONAL MAINTENANCE

In an organizational maintenance activity the AE maintains aircraft-installed secondary storage batteries. Secondary storage batteries are considered to be those that are rechargeable. (Primary reserve batteries are usually wet-cell batteries and are considered to be "one shot" or "delayed action" type batteries such as those used in missiles and some antisubmarine warfare (ASW) equipment. They are normally maintained by the rating that maintains the equipment in which the batteries are installed.

Of the secondary storage batteries, the lead-acid battery is the most widely used in aircraft today. Its discharge characteristics, in comparison with that of the nickel-cadmium and silver-zinc storage batteries, are shown in figure 5-1. It can be seen that of the three batteries the lead-acid battery is the least desirable because of its shorter discharge time and for this reason is being replaced by the nickel-cadmium storage

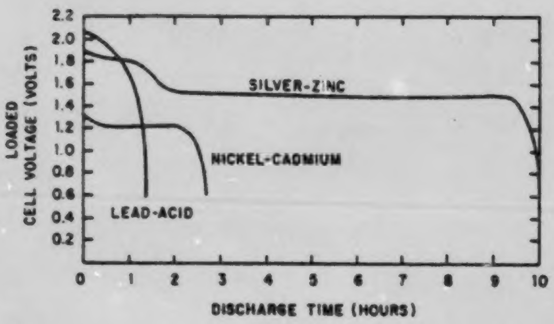


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Figure 5-1.—Discharge characteristics of secondary batteries of equal weight discharging under the same conditions.

battery in many aircraft. The cost of the silver-zinc battery makes its use prohibitive in most aircraft configurations. The silver-zinc battery, however, is used in several helicopters because of their high battery usage.

COLOR CODING

All acid batteries procured in the future must, by NavAir requirements, be furnished in pink cases and all alkaline batteries in blue cases, to avoid the mistaken identity of acid and alkaline batteries which leads to their being contaminated by the wrong electrolyte. Because indiscriminate use of the same tools on both types of batteries is a principal cause of contamination, the tools should also be painted these colors to assure that they will be used on only one kind of battery.

Electrolyte used in lead-acid batteries is a strong solution of sulphuric acid and distilled water. Anything associated with the lead-acid battery should never come in contact with the alkaline electrolyte or battery. Even acid fumes can damage the hardware of the nickel-cadmium or silver-zinc batteries. The AE should be particularly careful when using hydrometers or syringes.

Tools and equipment used on lead-acid batteries can be neutralized by rinsing in clean water, preferably hot water, then immersing in a solution of ammonia or sodium bicarbonate (baking soda), followed by an additional rinse with clear tap or distilled water. Vinegar or a boric acid solution may be used as a neutralizing agent for tools contaminated with potassium hydroxide (alkaline) solution. Also, water should be used freely to rinse the tools after neutralization.

A battery that is no longer fit for service in aircraft must be painted bright yellow and stenciled on both sides:

DO NOT INSTALL IN AIRCRAFT
FOR GROUND USE ONLY

These batteries may only be used on testing devices, battery carts, or other ground equipment.

QUICK-DISCONNECT UNIT

To make installation and removal of the battery quicker and easier, most batteries use a quick-disconnect unit to connect the power leads to the battery. This unit consists of a plug, which is attached to the end of the battery leads in the aircraft, and a receptacle, which is mounted on the terminal side of the battery. (See fig. 5-2.) The receptacle covers the battery terminal posts and prevents accidental shorting during installation and removal. The plug consists of a socket with a keyway to prevent reverse installation of the wires and a handwheel having a coarse-pitch thread. The several advantages of this unit are:

1. Only a few turns are required on the turnwheel to lock the connector in place.
2. No safety wire is required.
3. Accidental reversal of the leads is prevented.
4. In an emergency the battery may be disconnected in minimum time.
5. Both leads are connected or disconnected simultaneously.

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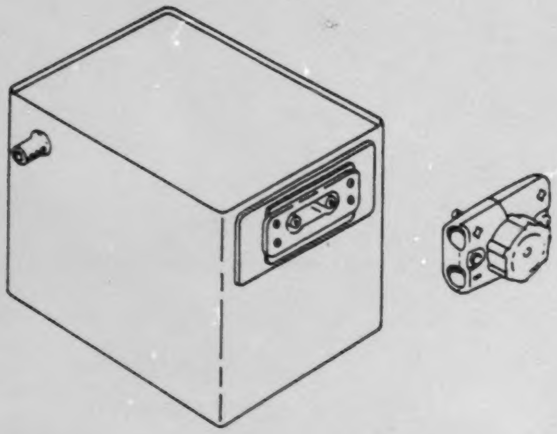

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Figure 5-2.—Typical aircraft storage battery with quick-disconnect unit.

BATTERY VENT SYSTEM

Wet-cell batteries, in general, emit some type of gas when being charged or discharged. This is especially true of lead-acid batteries and, to a lesser degree, the nickel-cadmium and silver-zinc batteries. For this reason a vent is provided, usually in the filler plug, for each cell to vent gas and moisture to the top of the battery. If allowed to stand on the top of the battery, the moisture could cause shorting of the cells and corrosion of the battery and external parts. Ventilation is provided by openings at each end of the battery which can be used for venting or draining.

In a vent system (fig. 5-3), the void above the cells and beneath the sealed cover is subjected to differential pressure areas on the skin of the aircraft through the vent nozzles level with the top of the cells on opposing sides of the battery container. As the battery is mounted in the aircraft, the higher of the two vent nozzles is connected to a rising vent tube which is exposed to a positive pressure area on the skin of the aircraft. This provides definite pressure on the battery in flight and acts as a chimney or flue for the light hydrogen gas when the aircraft is at rest. The lower of the two vent nozzles connects to a tube which is exposed to a negative pressure area on the skin of the aircraft and is physically lower than the battery vent nozzle.

When a battery drain sump is used, the discharge tube from the battery is connected to a glass jar sump and extends into the jar approximately 1 inch. The exhaust tube (from the sump jar), the end of which is cut off at a 30° angle and extends into the sump jar approximately one-third its depth, is routed to the skin surface of the aircraft. The sump jar normally contains a felt pad and, in the case of the lead-acid battery, will be moistened with a concentrated solution of sodium bicarbonate for neutralizing gases and excess battery solution.

When a sump jar is not used, the exhaust tube is connected to the nozzle of the battery which is lower when the aircraft is in a taxiing position, and is located in such a manner that battery acid may escape without injury to the aircraft.

Refer to the Maintenance Instructions Manual of the aircraft for specific directions concerning the maintenance of the particular vent-sump system that is used.

LEAD-ACID BATTERY

Because the lead-acid battery is similar in appearance to the alkaline battery, it is vitally important that part numbers be checked prior to installing or working on any battery. Personnel removing and replacing batteries should make certain that battery fluid (a mixture of sulphuric acid and water) does not splash in their eyes or on their clothing. If it is splashed in the eyes, flush generously with fresh water and report to a doctor immediately. If battery acid is spilled on clothing, rinse them with fresh water or a mixture of sodium bicarbonate and fresh water.

Battery Maintenance

A 14-day inspection has generally been accepted as adequate; however, some aircraft inspection intervals will vary and the applicable Periodic Maintenance Requirements Manual (PMRM) must be adhered to. The following items should normally be accomplished at the prescribed inspection interval:

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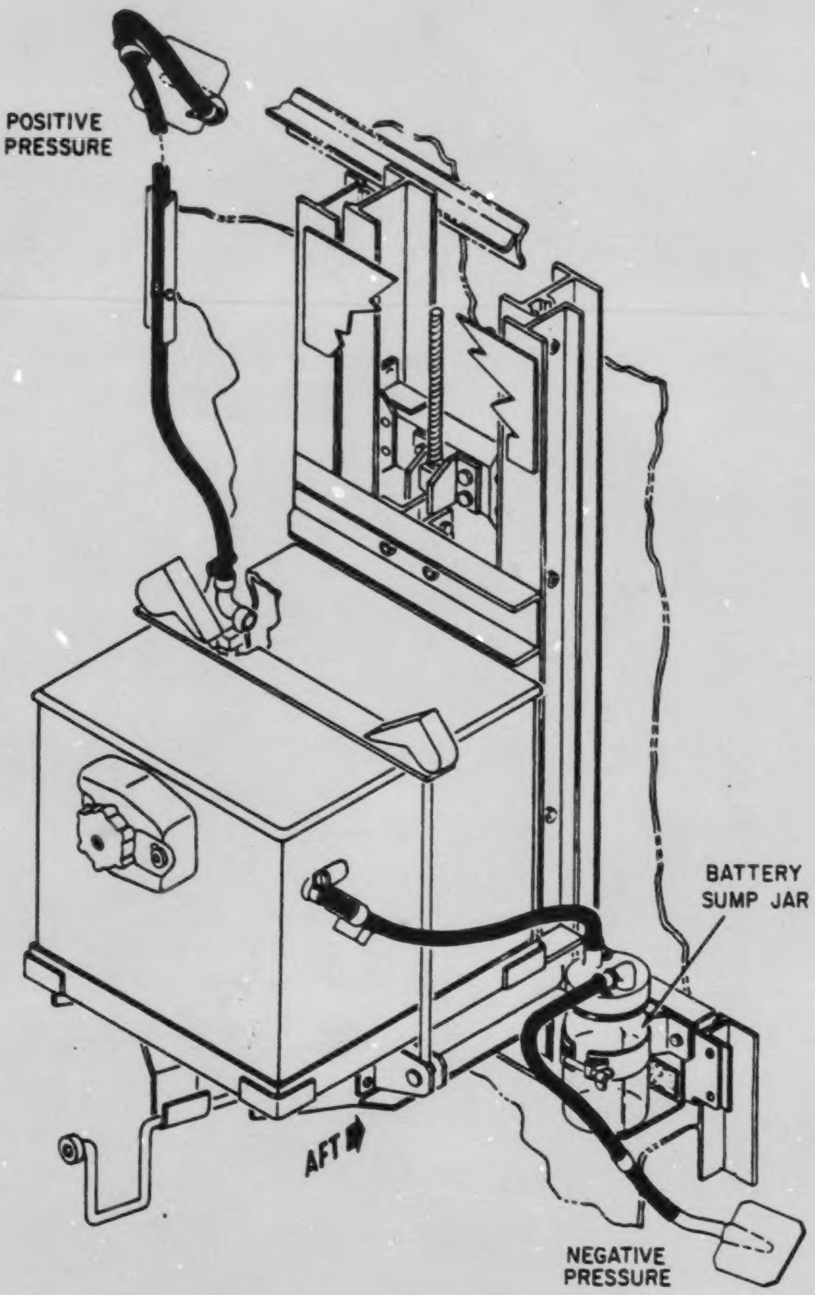
POSITIVE
PRESSURE
BATTERY
SUMP JAR
AFT
NEGATIVE
PRESSURE

AE.750

Figure 5-3.—Battery vent system.

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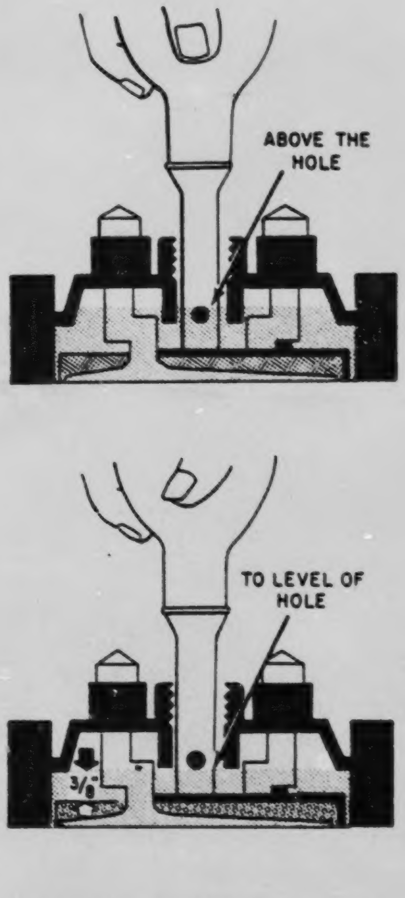
1. Check specific gravity. Correct for temperature, and replace battery if below 1.240 or above 1.310.
2. Add water if necessary. Fill to three-eighths inch above protector plates or as required by battery manufacturer.
3. Check terminals. Keep clean and tight.
4. Inspect sump (if used). Resaturate pad if dry.
5. Check mounting. Tighten if loose.
6. Inspect for leakage. Replace battery if leakage is indicated.
7. Inspect vent tubes and vent caps. Clean out if they are clogged.
8. Inspect battery lid gasket for proper condition.
9. Inspect battery lid for condition and proper fit.
10. Check aircraft voltage regulator setting for proper voltage.

When it is necessary to add water to a battery, use distilled water. Clean drinking water may be used only if distilled water is not available. There is no need to add water if the electrolyte level is three-eighths inch above the plates in a fully charged battery and the specific gravity readings can be taken with a hydrometer. If it is necessary to add water, use only enough to bring the electrolyte approximately three-eighths inch above the plates. The addition of too much water is just as detrimental to the battery as an insufficient amount. Too much water will cause the electrolyte to bubble out of the vents. This will not only weaken the electrolyte, but will also corrode the battery. Water is added by a self-leveling syringe (fig. 5-4). First, a little water is injected into the cell by squeezing the rubber ball. As you release the pressure, the surplus fluid returns to the ball. A small hole drilled through the stem of the syringe establishes the correct level of electrolyte. The correct level is reached when the fluid gets to the edge of the hole and ceases to return into the syringe.

Care must be taken when using the syringe so that the electrolyte is not withdrawn from the battery and transferred to a different cell or replaced with distilled water. Sulphuric acid or fresh electrolyte should never be added at the organizational level of maintenance. After adding water to a battery, every attempt should be made to insure that the water is mixed with the electrolyte. This may be accomplished by allowing the battery to charge for a minimum of 30 minutes.

A battery will also require removal and recharge if left in an unused aircraft for a period of 1 week or more, depending upon temperature. A fully charged battery will lose approximately one-half of its charge in the following number of days for the temperature given:

60° F	90 days
80° F	45 days
100° F	14 days
120° F	9 days



AE.94

Figure 5-4.—Self-leveling syringe.

Insulation breakdown between battery terminal and case may occur as a result of cracked insulation washers and sleeving of terminal feedthroughs. This can be attributed to excessive tightening of the terminal securing jamnuts and the presence of acid at this point through a fault in the acid-resistant plastic coating and bituminous cell sealing compound.

Cold Weather Operation and Maintenance

Recharge time is especially important in cold weather operations. At low temperatures the internal resistance of a battery is so high that the charging current drawn from a 27.7-volt aircraft electrical system is relatively small. Therefore, at low temperatures the battery charging rate is such that during a given flight the battery will usually not fully recharge.

When operating at temperatures of 0° F or below, batteries should be maintained at a fully charged level of 1.280 in order to avoid decreased efficiency due to a low charging rate. Batteries should be kept above 32° F whenever possible. Below -20° F, it is almost impossible to recharge a battery in flight.

Battery freezing may be attributed to a discharged battery, or water being added and the battery not placed on charge immediately. The relationship of specific gravity of the electrolyte to its freezing point is given in table 5-1. It is important that water never be added in freezing weather when batteries are to be left standing before charging. A leaking cell may result from adding water to a battery, which then freezes. If the electrolyte becomes frozen, it is always necessary to replace the battery although, in case of partial freezing, thawing in a warm room may save it. However, it should be thoroughly checked before being used in an aircraft.

When an aircraft located in below-zero temperatures is not in use, its battery should either be removed and kept in a warm place or heated in the aircraft. Do not attempt to keep the battery warm by charging, as continued overcharging is detrimental to its life.

Table 5-1.–Battery freezing points

Specific gravity	Freezing points degrees F.
1.300	-95°
1.275	-80°
1.250	-61°
1.225	-35°
1.200	-17°
1.175	- 4°
1.150	+ 5°
1.125	+13°
1.100	+18°
1.050	+26°
1.000 (water)	+32°

NICKEL-CADMIUM BATTERIES

Although the nickel-cadmium battery is in many ways similar in physical appearance to the lead-acid battery, its operation and maintenance are strikingly different. The electrolyte used in a nickel-cadmium battery is a 30-percent (by weight) solution of potassium hydroxide (KOH) and distilled water. The specific gravity of the electrolyte, when commissioning the battery, should be 1.300, and may vary with use between 1.240 and 1.320 without any appreciable effect on battery performance. However, since no chemical change of the electrolyte occurs during charging or discharging, the specific gravity will remain essentially constant and, therefore, cannot be used to determine the state of charge as with the lead-acid battery.

At present, a simple method of determining the exact state-of-charge has not been developed. The accepted method is to measure the voltage under loaded and no-load conditions both for the cell and for the complete battery. The applicable Maintenance Instructions Manual should provide the minimum voltage readings. As a general rule, however, the minimum cell no-load voltage should not be less than 1.4 volts, the battery voltage no less than the minimum cell voltage times the number of cells, and no more than 0.2 volt difference between the cell voltages.

Even the above method of charge determination is less than adequate because of the constant-voltage characteristics of the nickel-cadmium battery. (See fig. 5-1.) Therefore, the importance of periodic inspections becomes more apparent. The battery shop at an intermediate maintenance activity has the capability of determining the exact state-of-charge and should be used at regular intervals, usually during calendar inspection.

In addition to the above, the nickel-cadmium battery should be periodically inspected for the following:

1. Electrolyte level.
2. Excessive spewage.
3. Loose or corroded connectors.

Electrolyte Level

An inherent characteristic of nickel-cadmium cells is that when they are in a low or discharged condition, the electrolyte is absorbed within the plates and separators to a point where it is not visible from the top of the cells. When the battery is recharged, the electrolyte level rises. At full charge, the electrolyte level is at its maximum. Electrolyte or distilled water should be added only at an Intermediate maintenance activity.

If water is added to nickel-cadmium cells while the battery is in the aircraft and the state-of-charge is unknown, a chain reaction may be set off because of the high current drawn by the battery during flight. As the battery receives its charge from the aircraft bus, electrolyte may boil or spew through the cell vent caps. The potash contained in the electrolyte may eventually plug the vents of the cell caps. Also the density of the electrolyte is reduced by the loss of potash and results in loss of capacity. Should the vents become plugged, pressure immediately builds up in the cells, and gas accumulates. When sufficient pressure builds up, the electrolyte will be forced from the cells. It may then flow over the top of the cells and down into the case bottom between the cells. The overflow of electrolyte eventually starts corrosion and may cause a short circuit between the cell connectors. This chain of events, particularly the accumulation of hydrogen, can lead to an explosion. An igniting spark could be caused by a loose cell connection or a short circuit between the cell connectors resulting from the spewed electrolyte.

Excessive Spewage

Under normal operating conditions, nickel-cadmium batteries will usually remain clean except for possible dust which requires external cleaning of the case and cell tops. If overcharging is heavy, gassing and bubbling of electrolyte through the vent caps may cause formation of a white substance on top of the cells. This substance is potassium carbonate, which may be removed by brushing the cells with a stiff bristle brush. CAUTION: Under no circumstances use a wire brush for cleaning. Make sure cell vents are closed before attempting to clean.

If the electrolyte has overflowed to the extent that it has run down between the cells, the battery should be removed from the aircraft and sent to the battery shop.

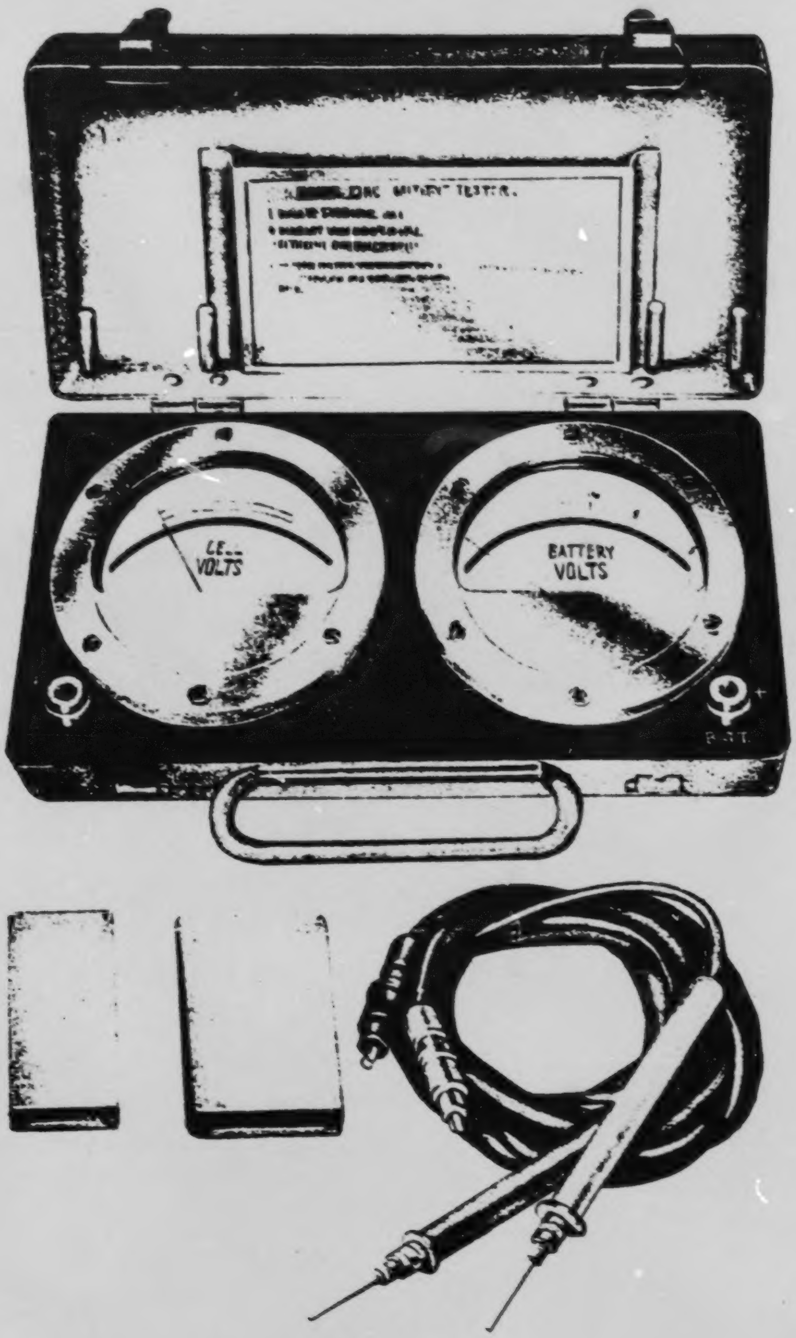
Loose or Corroded Connectors

Loose connectors or terminals may be detected by the appearance of burn marks on or near the connectors. These marks and any other corrosion must be cleaned before tightening the connectors. Care must be taken to tighten the connectors to the torque value required by the manufacturer's specifications. If excessive corrosion is noted, it may indicate cell to case leakage or a bad cell, and the battery must be removed from the aircraft and returned to the battery shop.

SILVER-ZINC BATTERIES

In general, silver-zinc batteries require maintenance which is similar in many respects to that which is required of the nickel-cadmium type batteries. Testing the battery's open circuit voltage is the method by which its state-of-charge is ascertained.

A silver-zinc battery tester (fig. 5-5) or a voltmeter which reads accurately to 0.1 volt should


VOLTS
BATTERY VOLTS

AE.102

Figure 5-5.—Silver-Zinc Battery Tester, Model RAC777.

be used to test the open circuit voltage of the battery. If the reading is below 25.6 volts, remove the battery cover and inspect the top of the battery for corrosion or damaged cells. If any damage is evident, remove and replace the battery.

Corrosion may be removed by wiping with a damp cloth. After all connections have been inspected and tightened, recheck the open circuit voltage. If the reading is still below 25.6 volts, check each cell voltage with the tester or voltmeter. Readings between 1.83 volts and 1.86 volts per cell will indicate that the battery is charged to at least 70 percent of its capacity. If the readings on any cell is below 1.83 volts, remove the battery from the aircraft.

If one or more cells read 1.60 volts or lower, while the others give higher readings, the battery has become unbalanced. The cause for this imbalance is usually an excessively high discharge rate. If this condition is left uncorrected, this imbalance on subsequent discharges will probably lead to cell reversal and battery failure. The battery must then be removed from the aircraft to be serviced in the battery shop.

Daily Inspection

The silver-zinc battery should normally be checked prior to the first flight of each day. The measurement of battery and/or cell terminal voltages must not be performed before a minimum of 2 hours has elapsed since operation of the battery in the aircraft. This is to allow the battery and cell voltages to stabilize after being charged. It is recommended that a daily check sheet similar to the one shown in figure 5-6 be used and retained on file for the time period established by local regulations.

LEAKAGE CHECK.–Place one lead of the voltmeter on the battery case and the other on a battery terminal. A reading of zero volts indicates no case voltage leak.

SERVICEABILITY CHECK.–Perform the serviceability check as follows:

1. Check open-circuit terminal voltage of the battery with a voltmeter which reads accurately to 0.1 volt. A reading of 25.6 volts or higher should be obtained. This terminal voltage reading should not be considered as positive proof of a satisfactory battery. It is possible that a silver-zinc battery might have 13 fully charged cells and one defective cell and still give a terminal voltage in excess of 25.6 volts.
2. Remove the cover from the battery and inspect the battery for corrosion, loose connections, or damaged cells. If corrosion is present, it may be removed with absorbent cotton or a clean damp rag after brushing with a nonconductive bristle brush. If the battery is damaged in any way, it must be removed and sent to the battery shop for servicing.
3. Check individual cell terminal voltages with a voltmeter accurate to 0.01 volt. The voltage of each cell must be 1.82 volts or higher.

Post-Flight Inspection

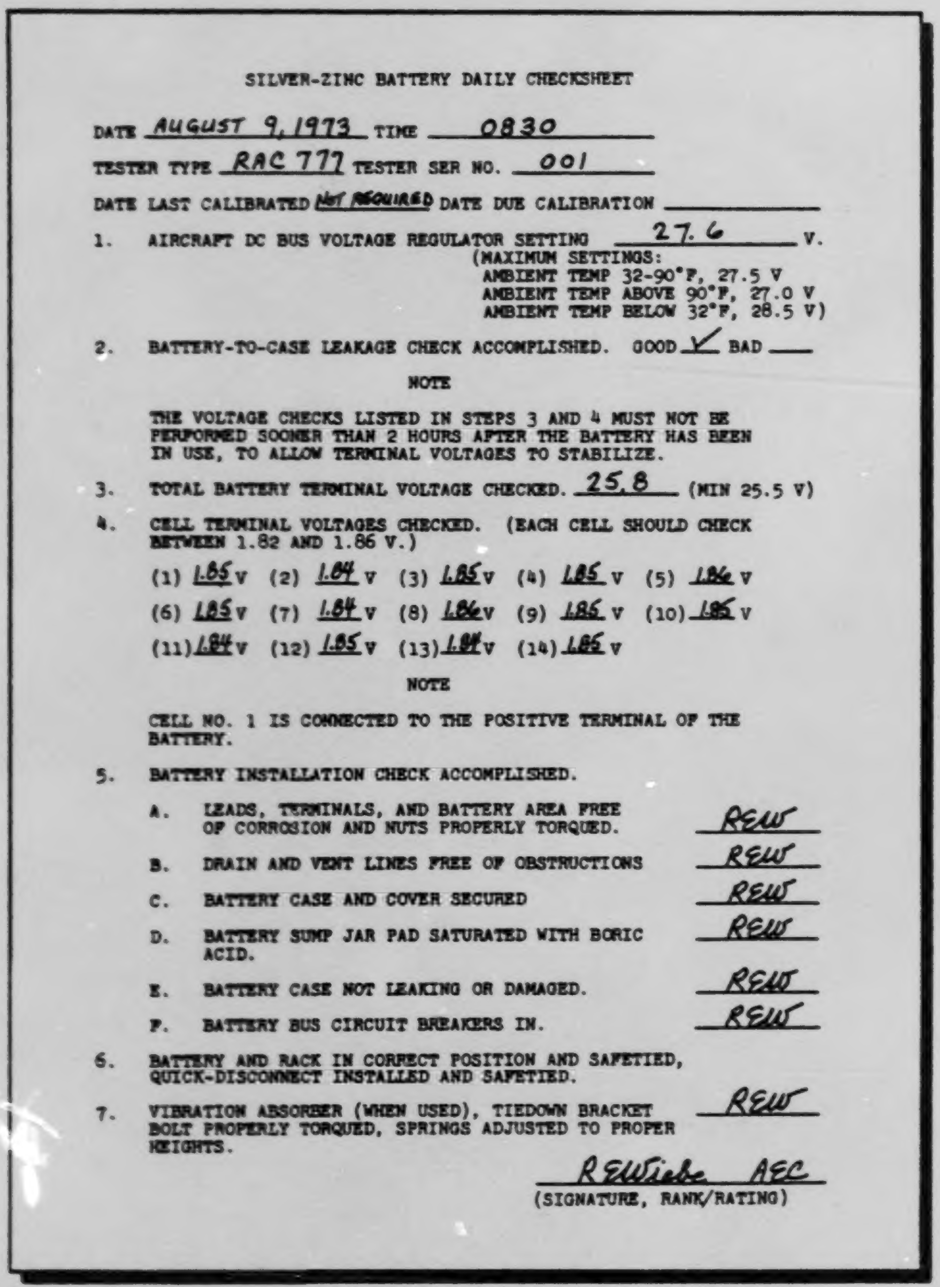
The silver-zinc battery will not give a steady open-circuit voltage reading immediately after charge or discharge, but must be provided time to allow the cell voltages to stabilize. It is therefore not practical to perform a post-flight inspection utilizing cell or battery terminal voltage measurements for a minimum of 2 hours after the aircraft has been in operation.

The following actions are recommended to prolong the service life of the silver-zinc battery in each organizational maintenance activity:

1. Disconnect the battery prior to application of external electrical power to the aircraft, when system operation permits.
2. Disconnect the battery and secure the access panel on weekends and holidays.
3. Remove the battery as required by the current Periodic Maintenance Requirements Manual and deliver it to the cognizant battery shop for electrolyte leveling.
4. Remove the battery from the aircraft and store it in an appropriate storage space whenever the aircraft is grounded for more than 24 hours.

INTERMEDIATE MAINTENANCE

The intermediate maintenance activity which was established as support for organizational



SILVER-ZINC BATTERY DAILY CHECKSHEET

DATE AUGUST 9, 1973 TIME 0830

TESTER TYPE RAC 777 TESTER SER NO. 001

DATE LAST CALIBRATED NOT REQUIRED DATE DUE CALIBRATION ____________

1. AIRCRAFT DC BUS VOLTAGE REGULATOR SETTING 27.6 V.
(MAXIMUM SETTINGS:
AMBIENT TEMP 32-90°F, 27.5 V
AMBIENT TEMP ABOVE 90°F, 27.0 V
AMBIENT TEMP BELOW 32°F, 28.5 V)

2. BATTERY-TO-CASE LEAKAGE CHECK ACCOMPLISHED. GOOD ✓ BAD ____

NOTE

THE VOLTAGE CHECKS LISTED IN STEPS 3 AND 4 MUST NOT BE PERFORMED SOONER THAN 2 HOURS AFTER THE BATTERY HAS BEEN IN USE, TO ALLOW TERMINAL VOLTAGES TO STABILIZE.

3. TOTAL BATTERY TERMINAL VOLTAGE CHECKED. 25.8 (MIN 25.5 V)

4. CELL TERMINAL VOLTAGES CHECKED. (EACH CELL SHOULD CHECK BETWEEN 1.82 AND 1.86 V.)

(1) 1.85 V (2) 1.84 V (3) 1.85 V (4) 1.85 V (5) 1.86 V
(6) 1.85 V (7) 1.84 V (8) 1.86 V (9) 1.86 V (10) 1.85 V
(11) 1.84 V (12) 1.85 V (13) 1.84 V (14) 1.85 V

NOTE

CELL NO. 1 IS CONNECTED TO THE POSITIVE TERMINAL OF THE BATTERY.

5. BATTERY INSTALLATION CHECK ACCOMPLISHED.

A. LEADS, TERMINALS, AND BATTERY AREA FREE OF CORROSION AND NUTS PROPERLY TORQUED. REW
B. DRAIN AND VENT LINES FREE OF OBSTRUCTIONS REW
C. BATTERY CASE AND COVER SECURED REW
D. BATTERY SUMP JAR PAD SATURATED WITH BORIC ACID. REW
E. BATTERY CASE NOT LEAKING OR DAMAGED. REW
F. BATTERY BUS CIRCUIT BREAKERS IN. REW

6. BATTERY AND RACK IN CORRECT POSITION AND SAFETIED, QUICK-DISCONNECT INSTALLED AND SAFETIED.

7. VIBRATION ABSORBER (WHEN USED), TIEDOWN BRACKET BOLT PROPERLY TORQUED, SPRINGS ADJUSTED TO PROPER HEIGHTS. REW

REWiebe AEC
(SIGNATURE, RANK/RATING)

AE.751

Figure 5-6.—Silver-zinc battery daily check-sheet.

4/83

level maintenance, houses the battery shop for battery maintenance. An aircraft battery shop includes the space and necessary facilities for servicing, repairing, charging, discharging, and testing of storage batteries currently in use in naval aircraft, as well as the storage batteries used in aircraft ground servicing equipment.

Due to the incompatibilities existing between the two basic electrolyte systems (acid and alkaline) in current batteries, separate battery shop facilities should be provided for the lead-acid and the alkaline batteries. As mentioned previously, shops, tools, and equipment should be color coded pink for acid and blue for alkaline batteries so that they will not be used interchangeably between the battery types. Further, the alkaline battery shop should be divided into two separate sections—nickel-cadmium and silver-zinc.

Because of the gasses emitted during charging and discharging of batteries, adequate ventilation is a necessity. Even the alkaline batteries are susceptible to runaway or overcharge which causes gassing. The ventilating system should be tied in directly with the charging equipment electric service to prevent inadvertent charging without ventilation.

A battery shop should be equipped with a deluge shower and eyewash fountain for emergencies. Also, materials necessary to counteract electrolyte burns, such as baking soda, lemon juice, ammonia, and boric acid should be readily available.

The following safety practices should be observed at all times when working in battery shops:

1. Only authorized personnel instructed in maintenance, precautions, and associated hazards should be assigned.
2. Smoking, open lights, uncovered switches, and flames must not be permitted where batteries are on charge. Appropriate warning signs must be posted.
3. Battery shops must be well ventilated.
4. Deluge shower or running water must be provided.
5. Until a shop is properly ventilated, never turn on lights, make or break electrical connections, or perform any work on batteries.
6. Do not make repairs to battery connections while circuits are energized.
7. Turn off charging current before batteries are connected to or disconnected from the charging line
8. Use only tools with insulated handles when servicing batteries.
9. Always pour acid into water while constantly stirring resultant mixture. Never pour water into concentrated acid because the chemical reaction will generate heat so rapidly that the solution will boil and may splash out of the container.
10. Wear approved goggles, gloves, aprons, and boots when handling electrolytes.
11. Be alert for sprays and splashes when opening containers and during mixing. If acid or potassium hydroxide spills, use the appropriate neutralizer and flush with an abundance of water.
12. If acid or potassium hydroxide is spilled or splashed on any part of the body, neutralize with the appropriate solution and immediately shower or flush affected areas with water. Should the eyes be affected, use the eye fountain and flush with an abundance of water, and seek medical attention immediately.
13. Insure that the battery shop is equipped at all times with first aid material, properly labeled, for neutralization of electrolytes that might come in contact with the eyes and skin.
14. Do not carry electrolyte in open-top containers, and insure that glass containers are protected against breakage.
15. Never permit containers of electrolyte to be placed near heating pipes or to stand in the sun.
16. Maintain the level of electrolyte in batteries above the tops of separators during charging.

The electrolyte used in nickel-cadmium and silver-zinc batteries is a caustic alkaline solution of potassium hydroxide as opposed to the sulphuric acid solution used in lead-acid batteries. The antidotes used when parts of the body are affected with potassium hydroxide differ from those used when the body is affected by sulphuric acid. Sulphuric acid burns may be neutralized by ammonia or baking soda and large amounts of water.

If an alkaline electrolyte gets on the skin, wash affected areas with large quantities of water or take a shower immediately. Neutralize with 3-percent acetic acid, vinegar, or lemon juice, and wash with water. If an alkaline electrolyte gets into the eyes, wash the eyes with a weak solution of boric acid or vinegar, and seek immediate medical attention. If an alkaline electrolyte has been taken internally, large quantities of water in a weak solution of lemon juice, orange juice, or vinegar should be drunk, followed by swallowing the white of an egg, olive oil, melted butter, starch water, or mineral oil. In all cases get medical attention as soon as possible.

Potassium hydroxide is somewhat corrosive to glass. All glass containers, hydrometers, or other devices used that contain glass should be thoroughly washed after their contact with the electrolyte.

BATTERY RECORDS

Proper maintenance is essential if the battery is to achieve maximum life and performance. Associated with good maintenance practices is the keeping of accurate records. These records serve as a verification of maintenance accomplished and provide information for determining usage rates, for establishing optimum servicing procedures, and for determining the causes for removal from aircraft.

The records should provide for entries on battery type, manufacturer, date commissioned or initially placed into service, charging information, specific gravity and temperature readings, capacity test results, specific application, dates in and out of shop, and other applicable information. A recommended format for the individual battery record is shown in figure 5-7. A form of this type which can be made on a standard 5" by 7" card, is recommended for each battery received and serviced or handled in the battery shop.

As a supplement to the individual battery record, a test record to show tests actually performed and the results of these tests should be kept. Recommended test record forms for the three types of batteries are shown in figures 5-8, 5-9, and 5-10.

LEAD–ACID BATTERIES

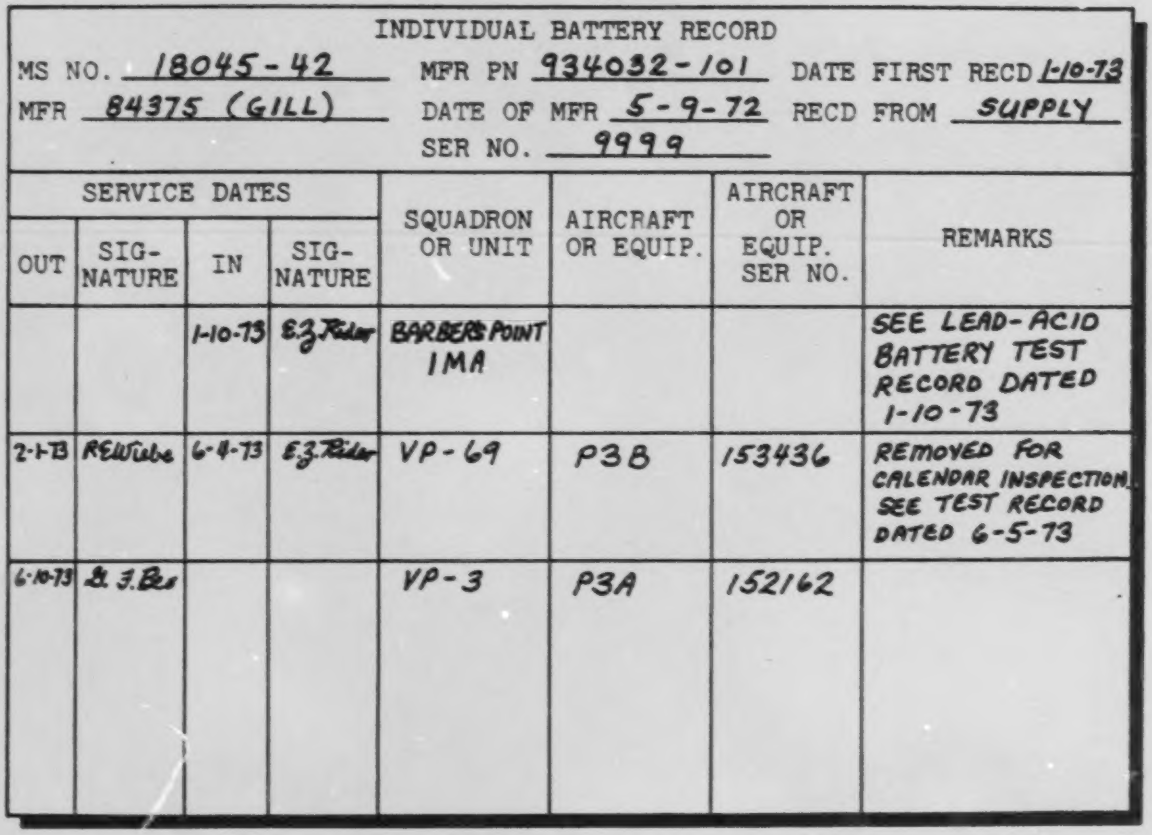
New batteries are shipped and stored without electrolyte in them, but with the plates dry-charged. Dry lead-acid batteries are to be filled with a solution of sulfuric acid having a specific gravity as recommended by the battery manufacturer. Specific gravity should be approximately 1.275, but this may differ in accordance with the manufacturer's instructions.

To add electrolyte to a battery, fill each cell with electrolyte prepared to the proper specific gravity, usually 1.275. The temperature of the electrolyte used should never exceed 90° F. Fill the battery to three-eighths inch above the protectors on top of the separators. Allow the battery to stand at least 1 hour after filling with electrolyte. If the level has fallen, add more electrolyte to restore it and replace the vent plugs. If electrolyte is spilled on the battery, it should be removed with a soda solution, being careful not to allow the solution to get into the cells. The battery should then be flushed with fresh water.

If time permits after a new dry-charged battery has been filled, it should be given an initial charge in accordance with instructions furnished by the manufacturer. In the absence of instructions, the first charge should be given at the finishing rate stated on the battery nameplate. This charge should be continued until the voltage and specific gravities of all cells show no increase over a period of 2 hours. If the temperature of the battery exceeds 100° F, the charge should be stopped until the temperature falls below 100° F.

Usually no adjustment of the specific gravity is necessary, but if it should exceed 1.300 in any cell, it should be reduced to some value between 1.275 and 1.300. The specific gravity can be reduced by removing some electrolyte with a hydrometer syringe and replacing it with distilled or clean drinking water.

When it is necessary to mix electrolyte, 1 part of concentrated acid should be mixed with 2 3/4 parts of distilled or clean drinking water by volume. Mixing should be done in a lead-lined tank. Glass or earthenware vessels may crack by the heat generated. After the electrolyte has cooled to about room temperature, stir it thoroughly and measure the specific gravity. This specific gravity may then be adjusted to the desired value by adding small amounts of water or acid as required.



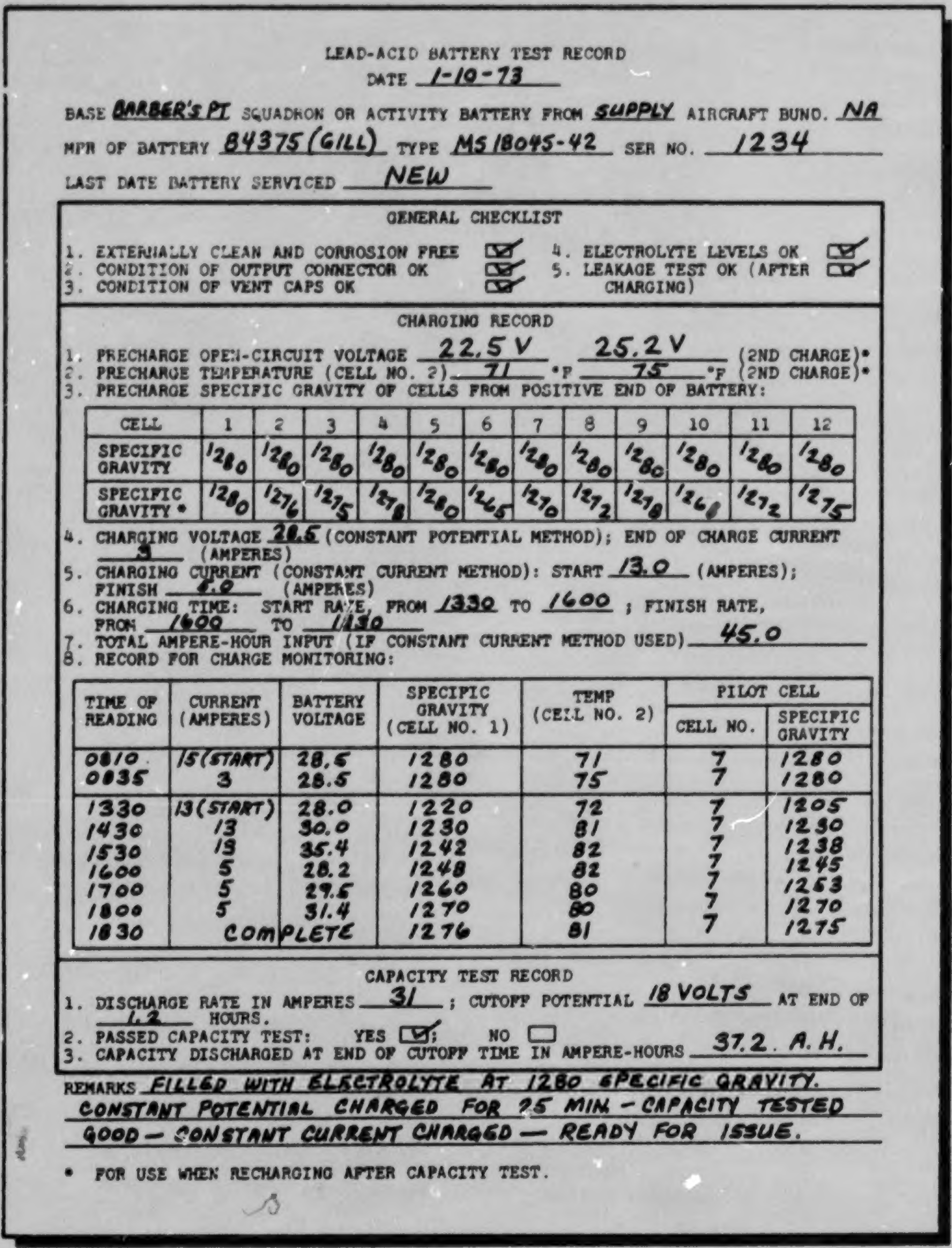
INDIVIDUAL BATTERY RECORD

MS NO. 18045-42 MFR PN 934032-101 DATE FIRST RECD 1-10-73
MFR 84375 (GILL) DATE OF MFR 5-9-72 RECD FROM SUPPLY
SER NO. 9999

SERVICE DATES				SQUADRON OR UNIT	AIRCRAFT OR EQUIP.	AIRCRAFT OR EQUIP. SER NO.	REMARKS
OUT	SIG-NATURE	IN	SIG-NATURE				
		1-10-73	E.J. Rider	BARBERS POINT IMA			SEE LEAD-ACID BATTERY TEST RECORD DATED 1-10-73
2-1-73	R.E. Wiebe	6-4-73	E.J. Rider	VP-69	P3B	153436	REMOVED FOR CALENDAR INSPECTION. SEE TEST RECORD DATED 6-5-73
6-10-73	D. J. Bes			VP-3	P3A	152162	

AE.752

Figure 5-7.—Individual battery record form.



LEAD-ACID BATTERY TEST RECORD

DATE 1-10-73

BASE BARBER'S PT SQUADRON OR ACTIVITY BATTERY FROM SUPPLY AIRCRAFT BUNO. NA

MFR OF BATTERY 84375 (GILL) TYPE MS18045-42 SER NO. 1234

LAST DATE BATTERY SERVICED NEW

GENERAL CHECKLIST

1. EXTERNALLY CLEAN AND CORROSION FREE ☑
2. CONDITION OF OUTPUT CONNECTOR OK ☑
3. CONDITION OF VENT CAPS OK ☑
4. ELECTROLYTE LEVELS OK ☑
5. LEAKAGE TEST OK (AFTER CHARGING) ☑

CHARGING RECORD

1. PRECHARGE OPEN-CIRCUIT VOLTAGE 22.5 V 25.2 V (2ND CHARGE)*
2. PRECHARGE TEMPERATURE (CELL NO. 2) 71 °F 75 °F (2ND CHARGE)*
3. PRECHARGE SPECIFIC GRAVITY OF CELLS FROM POSITIVE END OF BATTERY:

CELL	1	2	3	4	5	6	7	8	9	10	11	12
SPECIFIC GRAVITY	1280	1280	1280	1280	1280	1280	1280	1280	1280	1280	1280	1280
SPECIFIC GRAVITY *	1280	1276	1275	1278	1280	1265	1270	1272	1278	1268	1272	1275

4. CHARGING VOLTAGE 28.5 (CONSTANT POTENTIAL METHOD); END OF CHARGE CURRENT 3 (AMPERES)
5. CHARGING CURRENT (CONSTANT CURRENT METHOD): START 13.0 (AMPERES); FINISH 5.0 (AMPERES)
6. CHARGING TIME: START RATE, FROM 1330 TO 1600 ; FINISH RATE, FROM 1600 TO 1830
7. TOTAL AMPERE-HOUR INPUT (IF CONSTANT CURRENT METHOD USED) 45.0
8. RECORD FOR CHARGE MONITORING:

TIME OF READING	CURRENT (AMPERES)	BATTERY VOLTAGE	SPECIFIC GRAVITY (CELL NO. 1)	TEMP (CELL NO. 2)	PILOT CELL	
					CELL NO.	SPECIFIC GRAVITY
0810	15 (START)	28.5	1280	71	7	1280
0835	3	28.5	1280	75	7	1280
1330	13 (START)	28.0	1220	72	7	1205
1430	13	30.0	1230	81	7	1230
1530	13	35.4	1242	82	7	1238
1600	5	28.2	1248	82	7	1245
1700	5	29.5	1260	80	7	1253
1800	5	31.4	1270	80	7	1270
1830	COMPLETE		1276	81	7	1275

CAPACITY TEST RECORD

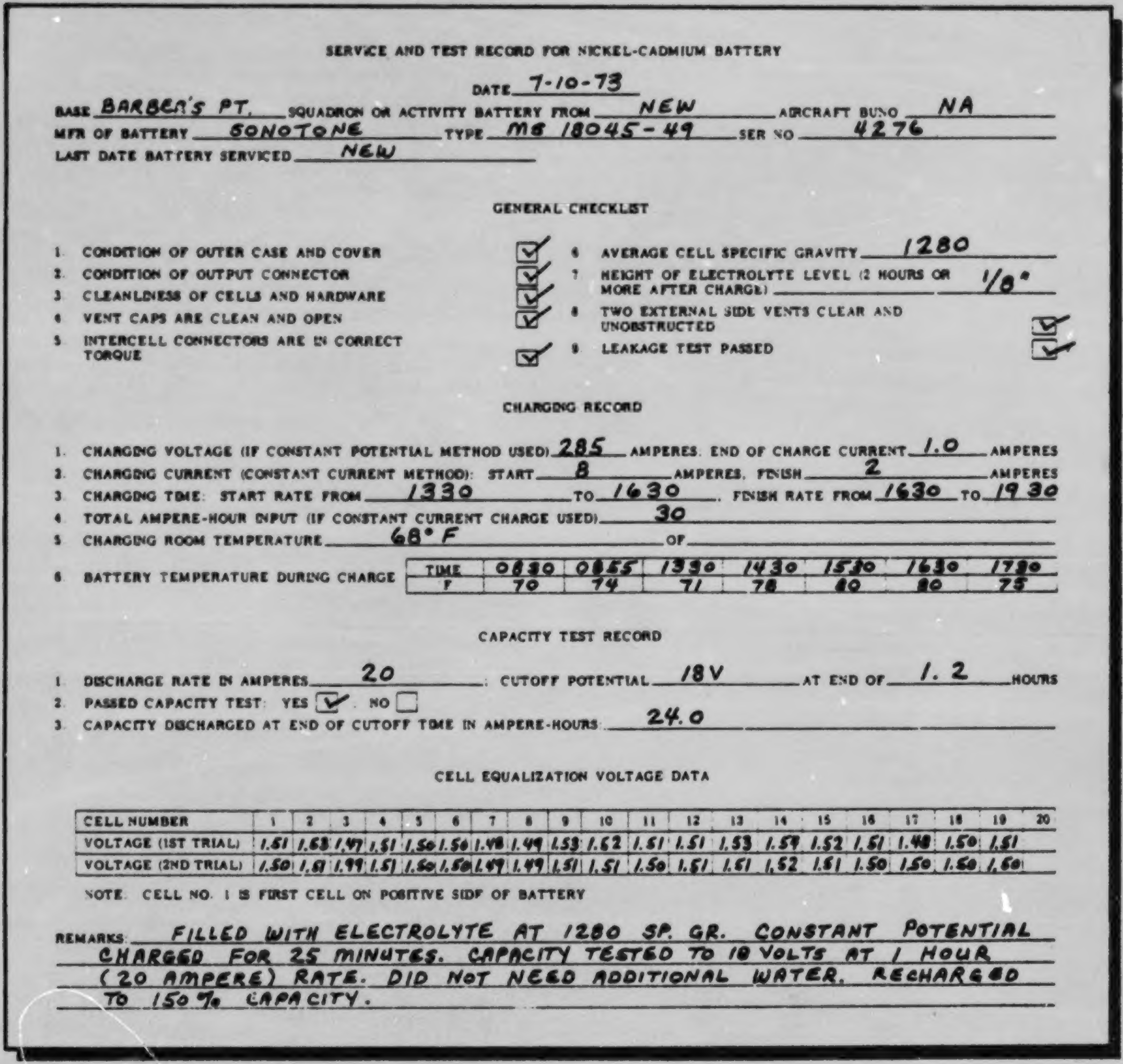
1. DISCHARGE RATE IN AMPERES 31 ; CUTOFF POTENTIAL 18 VOLTS AT END OF 1.2 HOURS.
2. PASSED CAPACITY TEST: YES ☑; NO ☐
3. CAPACITY DISCHARGED AT END OF CUTOFF TIME IN AMPERE-HOURS 37.2 A. H.

REMARKS FILLED WITH ELECTROLYTE AT 1280 SPECIFIC GRAVITY. CONSTANT POTENTIAL CHARGED FOR 25 MIN - CAPACITY TESTED GOOD — CONSTANT CURRENT CHARGED — READY FOR ISSUE.

* FOR USE WHEN RECHARGING AFTER CAPACITY TEST.

AE.753

Figure 5-8.—Battery test record form recommended for recording charging and capacity test data.



SERVICE AND TEST RECORD FOR NICKEL-CADMIUM BATTERY

DATE 7-10-73

BASE BARBER'S PT. SQUADRON OR ACTIVITY BATTERY FROM NEW AIRCRAFT BUNO NA

MFR OF BATTERY SONOTONE TYPE MS 18045-49 SER NO 4276

LAST DATE BATTERY SERVICED NEW

GENERAL CHECKLIST

1. CONDITION OF OUTER CASE AND COVER ☑
2. CONDITION OF OUTPUT CONNECTOR ☑
3. CLEANLINESS OF CELLS AND HARDWARE ☑
4. VENT CAPS ARE CLEAN AND OPEN ☑
5. INTERCELL CONNECTORS ARE IN CORRECT TORQUE ☑
6. AVERAGE CELL SPECIFIC GRAVITY 1280
7. HEIGHT OF ELECTROLYTE LEVEL (2 HOURS OR MORE AFTER CHARGE) 1/8"
8. TWO EXTERNAL SIDE VENTS CLEAR AND UNOBSTRUCTED ☑
9. LEAKAGE TEST PASSED ☑

CHARGING RECORD

1. CHARGING VOLTAGE (IF CONSTANT POTENTIAL METHOD USED) 285 AMPERES. END OF CHARGE CURRENT 1.0 AMPERES
2. CHARGING CURRENT (CONSTANT CURRENT METHOD): START 8 AMPERES, FINISH 2 AMPERES
3. CHARGING TIME: START RATE FROM 1330 TO 1630. FINISH RATE FROM 1630 TO 1930
4. TOTAL AMPERE-HOUR INPUT (IF CONSTANT CURRENT CHARGE USED) 30
5. CHARGING ROOM TEMPERATURE 68° F OF
6. BATTERY TEMPERATURE DURING CHARGE

TIME	0830	0855	1330	1430	1530	1630	1730
F	70	74	71	78	80	80	75

CAPACITY TEST RECORD

1. DISCHARGE RATE IN AMPERES 20 ; CUTOFF POTENTIAL 18V AT END OF 1.2 HOURS
2. PASSED CAPACITY TEST: YES ☑ NO ☐
3. CAPACITY DISCHARGED AT END OF CUTOFF TIME IN AMPERE-HOURS 24.0

CELL EQUALIZATION VOLTAGE DATA

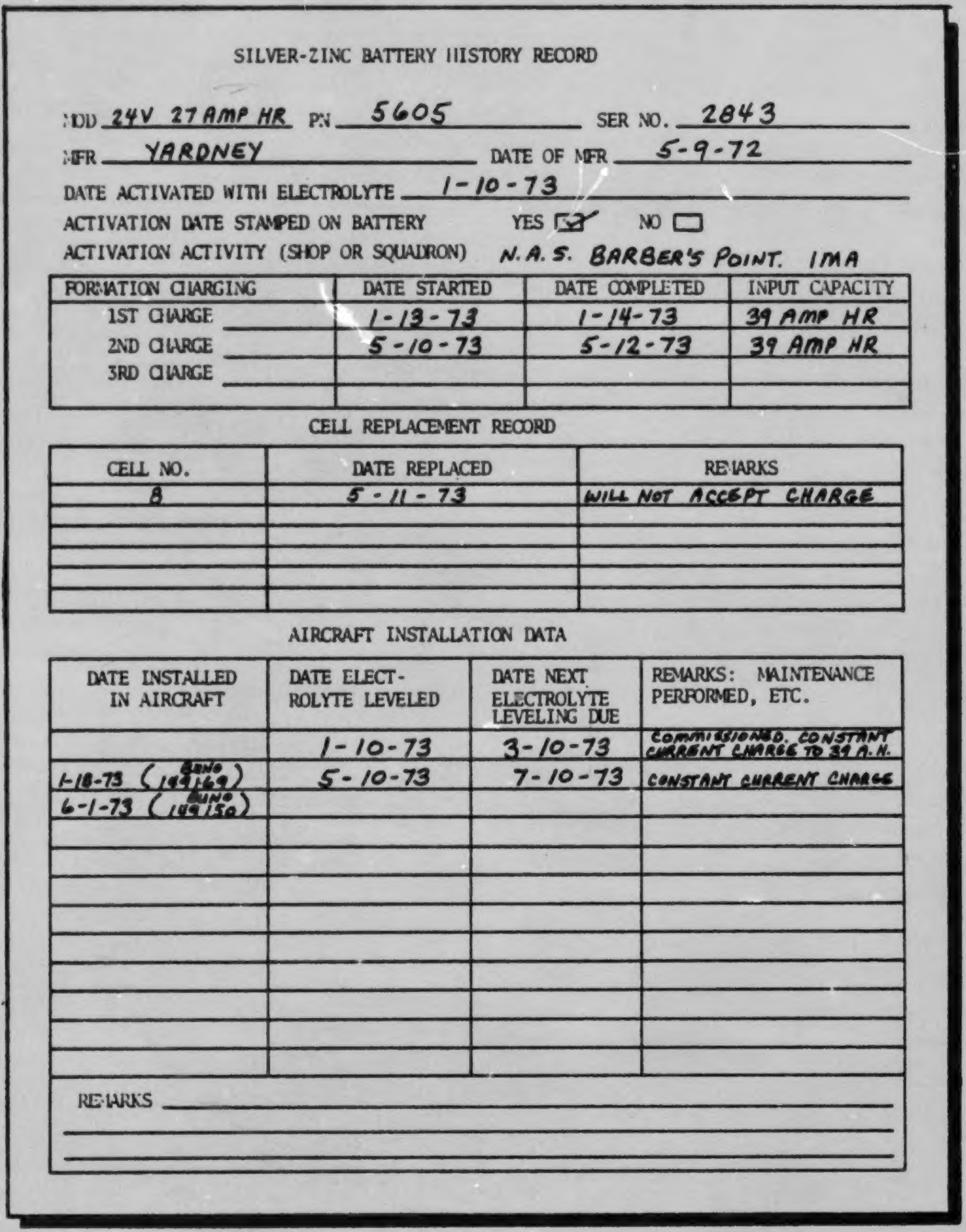
CELL NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
VOLTAGE (1ST TRIAL)	1.51	1.53	1.47	1.51	1.50	1.50	1.48	1.49	1.53	1.52	1.51	1.51	1.53	1.54	1.52	1.51	1.48	1.50	1.51	
VOLTAGE (2ND TRIAL)	1.50	1.51	1.49	1.51	1.50	1.50	1.49	1.49	1.51	1.51	1.50	1.51	1.51	1.52	1.51	1.50	1.50	1.50	1.50	

NOTE: CELL NO. 1 IS FIRST CELL ON POSITIVE SIDE OF BATTERY

REMARKS: FILLED WITH ELECTROLYTE AT 1280 SP. GR. CONSTANT POTENTIAL CHARGED FOR 25 MINUTES. CAPACITY TESTED TO 18 VOLTS AT 1 HOUR (20 AMPERE) RATE. DID NOT NEED ADDITIONAL WATER. RECHARGED TO 150% CAPACITY.

AE.754

Figure 5-9.—Service and test record form for nickel-cadmium batteries.



SILVER-ZINC BATTERY HISTORY RECORD

MOD 24V 27 AMP HR P/N 5605 SER NO. 2843

MFR YARDNEY DATE OF MFR 5-9-72

DATE ACTIVATED WITH ELECTROLYTE 1-10-73

ACTIVATION DATE STAMPED ON BATTERY YES ☑ NO ☐

ACTIVATION ACTIVITY (SHOP OR SQUADRON) N.A.S. BARBER'S POINT. IMA

FORMATION CHARGING	DATE STARTED	DATE COMPLETED	INPUT CAPACITY
1ST CHARGE	1-13-73	1-14-73	39 AMP HR
2ND CHARGE	5-10-73	5-12-73	39 AMP HR
3RD CHARGE			

CELL REPLACEMENT RECORD

CELL NO.	DATE REPLACED	REMARKS
8	5-11-73	WILL NOT ACCEPT CHARGE

AIRCRAFT INSTALLATION DATA

DATE INSTALLED IN AIRCRAFT	DATE ELECTROLYTE LEVELED	DATE NEXT ELECTROLYTE LEVELING DUE	REMARKS: MAINTENANCE PERFORMED, ETC.
	1-10-73	3-10-73	COMMISSIONED. CONSTANT CURRENT CHARGE TO 39 A.H.
1-18-73 (BUNO 149169)	5-10-73	7-10-73	CONSTANT CURRENT CHARGE
6-1-73 (BUNO 149150)			

REMARKS

AE.755

Figure 5-10.–Silver-zinc battery history record.

Charging/Discharging Equipment and Systems

Charging equipment for the lead-acid battery will vary from one activity to another. This equipment may be classified into three major categories:

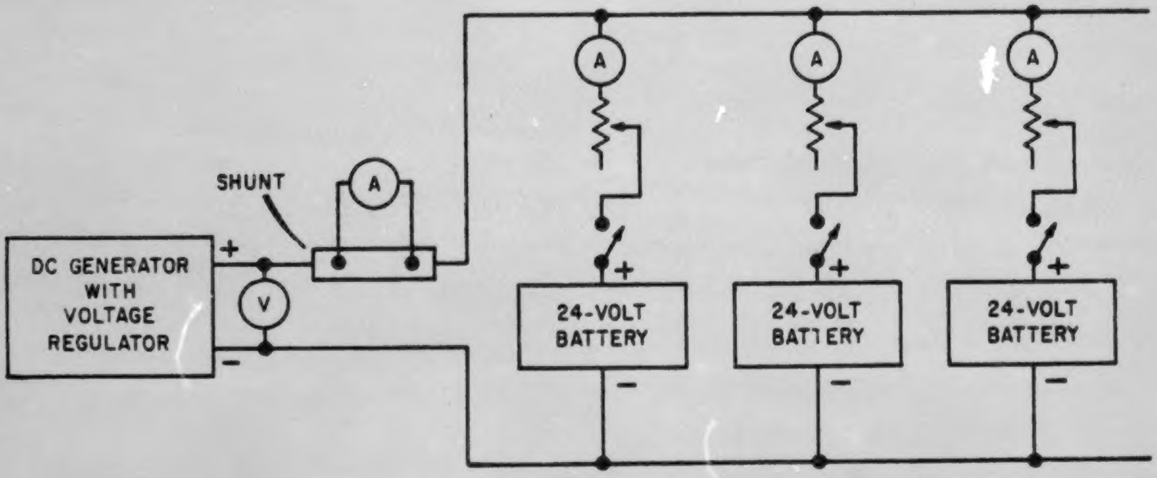
1. Constant potential chargers.
2. Constant current chargers.
3. Automatic chargers/dischargers.

CONSTANT POTENTIAL CHARGING SYSTEM.–Motor-generator sets used for constant potential charging must be capable of providing extremely close voltage regulation. Bus voltages are maintained at 28.5 volts, and when 24-volt batteries are being charged, a 250-watt 0.1 ohm current-limiting resistor is inserted between each battery and the bus. Two 12-volt batteries may be connected in series across the 28.5-volt bus if they have equal capacity ratings and have been discharged approximately the same amount. The initial charging current will be high but will gradually decline. For example, a 31-ampere-hour 24-volt battery can be considered charged when the charging current decreases to 3 amperes or when three consecutive specific gravity readings taken at 30-minute intervals are the same. The corresponding final charging current for other sizes of batteries will be proportionately more or less than that for the 31-ampere-hour battery, depending on their ampere-hour ratings.

A modified constant potential system can be obtained by installing a potentiometer in each charging circuit in series with a precision ammeter. By potentiometer adjustment, initial charging current can be limited to that recommended for the specific type battery being charged. (See fig. 5-11.)

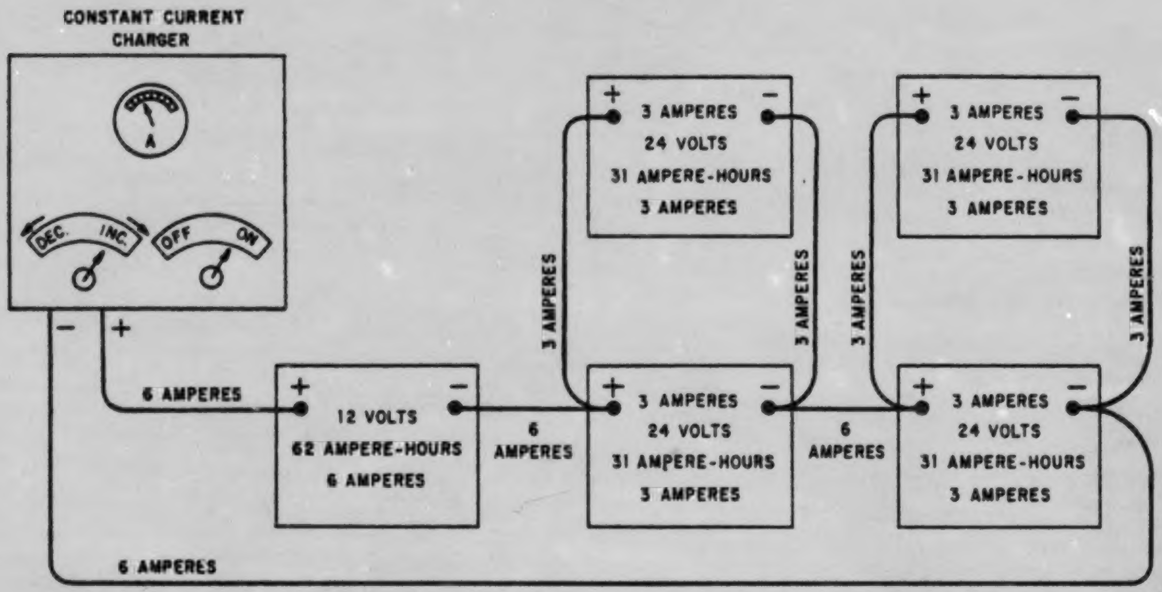
CONSTANT CURRENT CHARGING SYSTEM.– A common method of charging lead-acid batteries is by the constant current charging system. In this system a current of the same value is passed through all batteries in the same line. The voltage and capacity of the batteries determine the type of connections to be made, and generally all batteries should have the same ratings. However, some variations can be made to match the batteries as shown in figure 5-12.

The battery nameplate shows START and FINISH charging rates in amperes for constant current charging. The start rate is used until the



AE.756

Figure 5-11.–Circuit for modified constant potential charging of batteries.



AE.757

Figure 5-12.—Circuit for constant current charging two sizes of batteries.

battery begins to gas freely, after which the finish rate is used. When batteries with different ampere-hour ratings are to be charged in the same string, the maximum charging current will be determined by the battery with the lowest ampere-hour rating. For best performance, a completely discharged battery should be charged to approximately 140 percent of its rated ampere-hour capacity.

Consider a 20-ampere-hour battery that is fully discharged (specific gravity of 1.130) and is in otherwise good condition. The nameplate data specifies a START rate of 8 amperes and a FINISH rate of 3 amperes. Assume the battery is placed on charge and begins to gas freely after 2 hours. The rate is then changed to 3 amperes, and the battery is charged for an additional 4 hours. The total input is 28 ampere-hours, or 140 percent of rated capacity. A battery in a partially charged condition would take proportionately less time to become fully charged.

CONSTANT POTENTIAL ADVANTAGES.—The constant POTENTIAL charging method is generally used in present-day battery shops because of the following advantages over the constant CURRENT method:

1. It is more practical where large quantities of batteries are processed, with the present equipment types available.
2. Batteries are charged more rapidly with less attention.
3. There is less danger of gassing at an excessive rate.
4. Batteries of the same nominal voltage, but of different capacities, can be connected in parallel directly to the charging source.
5. Batteries can be placed on charge or terminated independently of each other.

AUTOMATIC CHARGE/DISCHARGE EQUIPMENTS.—Some installations are now equipped with equipment designed to charge and discharge batteries automatically. The discharge cycle is provided to perform a capacity test of the battery after it has been charged. One such test set, the AN/USM-104, was designed for 18-ampere-hour and 31-ampere-hour 24-volt lead-acid batteries. The set is portable and

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requires only that an operator make the necessary connections, start the equipment, and disconnect the battery when finished. The maximum length of time required to service a battery completely is 8 hours.

The operation of the AN/USM-104 consists of three automatic cycles:

1. The battery is charged until the charging current reaches 4 amperes, or for 3 hours, whichever occurs first.
2. The battery is discharged at a 2-hour rate (9 amperes and 15.5 amperes for the 18-ampere-hour and 31-ampere-hour batteries respectively). At the end of this period the battery voltage must be a minimum of 19 volts to advance to cycle 3.
3. The battery is recharged until the charging current diminishes to 4 amperes, or for a maximum of 3 hours.

Preparing Battery for Charging

The battery that has been in service should be prepared as follows before being placed on charge:

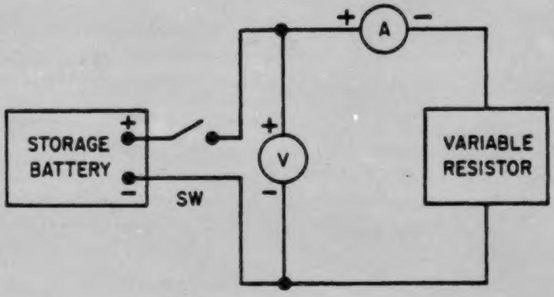
1. Clean the outside and top of the battery with a hose and plenty of water. Remove any corrosion that may be on terminals or other areas with a solution of bicarbonate of soda. Insure that soda solution does not enter cell or vent caps. Check the physical condition of the battery.
2. Remove the filler caps and inspect the battery internally. If the electrolyte level is low, add distilled water (or drinking water if distilled water is not available) to bring the level of the electrolyte to approximately three-eights inch above the protector on top of the separators, or to the level recommended by the battery manufacturer.
3. Unscrew the vent caps but leave them in the cell openings to prevent spraying of electrolyte from the battery while charging, and to prevent foreign matter from falling into cells.

CAUTION: Battery maintenance personnel should exercise extreme caution when attaching or removing battery leads to prevent short circuit flashes. Hydrogen gas generated in the cells during charging may ignite and cause an explosion. Insure that the charging current is off when connecting or disconnecting leads to batteries.

Capacity Testing

To capacity test a lead-acid battery with nonautomatic equipment, perform the following procedures:

1. Give the battery full charge and overcharge for 2 hours at the finish rate, or until the battery has been charged to approximately 155 percent of its rated capacity. (For example, consider a 24-volt 31-ampere-hour battery that is fully discharged. With use of constant current charge the battery could adequately be charged for capacity test by charging at constant current of 10 amperes for 4 hours and then at 3 amperes for 3 hours. This would provide an input of 49 ampere-hours, or approximately 155 percent of the 31-ampere-hour rating of battery.)
2. Check the specific gravity of all cells after charge. Adjust the specific gravity if above 1.300 or below 1.260.
3. Allow the battery to rest and cool for a few hours, preferably overnight.
4. Record electrolyte temperature, open circuit voltage, range of cell specific gravities, and battery identification data on a form similar to that shown in figure 5-8.
5. Connect the battery to the discharger or to the circuit with an appropriate variable resistor, ammeter, voltmeter, and switch, as indicated in figure 5-13. Leave the switch in the open position.



AE.758

Figure 5-13.—Circuit connections for capacity test.

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6. Adjust the variable resistor for maximum resistance, and adjust the meters to the proper current and voltage ranges.

7. Close the discharge switch, and adjust the resistor to give a 1-hour discharge rate in amperes. Maintain this current constant throughout the test.

8. Monitor the current, terminal voltage, and electrolyte temperature at 15-minute intervals for the first one-half hour, and then every 5 or 10 minutes.

9. Record the time at cutoff of 18.0 volts for a 24-volt battery, or 9.0 volts for a 12-volt battery. To pass the test, this value of cutoff voltage should occur not less than 54 minutes after start of discharge.

10. Take specific gravity readings about 1 hour after termination of the test. The difference between initial and final specific gravity readings should be approximately equal for the different cells. An abnormally small difference between values in a cell, as compared with the differences in values of other cells, indicates retarded circulation of electrolyte. One important purpose of the capacity test is to spot defective cells in the battery.

If the battery fails the capacity test, additional charges and capacity tests may be made if conditions warrant. Often, batteries that fail an initial test will pass later tests. This might apply to a partially sulphated battery.

NICKEL-CADMIUM BATTERIES

The principal difference between the nickel-cadmium and lead-acid batteries is the type of electrolyte. The importance of maintaining separate facilities, tools, and equipment cannot be overemphasized. In addition to the incompatibility of sulphuric acid and potassium-hydroxide electrolytes so far as operation and destruction of material is concerned, the safety aspect is also vitally important. Neutralization and first aid procedures are entirely different. As stated previously, the alkaline battery shop and all of the tools and equipment in it should be painted blue, and the lead-acid related equipment should be painted pink.

The nickel-cadmium battery is capable of accepting the same types of charges as discussed under lead-acid batteries. However, the constant current method is preferred because of the difficulty in determining the state of charge. The voltage and electrolyte specific gravity will not change appreciably throughout the charge or discharge cycle. With a constant potential applied, a battery with only a few ampere hours of capacity left will accept very nearly the same amount of charging current as a battery with nearly full capacity.

General Charging Practices

The following general charging practices should be observed when charging the nickel-cadmium battery:

1. Charging is most efficient at battery temperatures between 40° F and 80° F.

2. Two or more batteries may be charged in parallel on a constant potential charging bus, provided the charging equipment has the proper current producing capability.

3. Do not connect two or more batteries in series when using the constant current method unless the batteries are of the same type and capacity and in the same state of discharge.

4. Do not charge individual cells unless the plastic case is supported on each side. A special frame may be built to fit the cell, or two boards or plates may be placed on each side of the cell and held together by a C-clamp. The sides of the cell must be kept flat during charging.

5. Perform necessary inspection, cleaning, and repairs before charging.

6. Do not energize charging equipment until after the battery has been connected to the charging circuit.

7. When charging a battery in the shop, a thermometer should be placed between the central cells in such a manner that the bulb of the thermometer is located below the top of the cells. Do not place on charge any battery that has a temperature of 100° F or higher.

8. Battery charging data should be entered on a form similar to that shown in figure 5-9.

9. Although foam will sometimes be noticed in cells during charge, it does not indicate a defect and is harmful only if it results in overflow and causes grounds or corrosion. *For plastic-cased cells only*: If there is enough foam

to spill, it may be floated off during the end of charge by filling the cell to the brim with electrolyte. After most of the foam has been eliminated, reduce the electrolyte to the proper level, and clean the vents and gaskets in water and reinstall. If required, discharge the battery, disassemble, and clean with water, but do not get water into the cells. Dry all parts thoroughly, reassemble, charge, and then return the battery to service. Foaming is more likely to occur after adding water, but it will usually disappear after a few cycles of operation.

Constant Current Charging

The time required to charge a nickel-cadmium battery by the constant current method depends on the amount of charge already in the battery, the charging current, and the capacity rating. If fully discharged, the battery should be charged to 150 percent of its nominal ampere-hour rating. It may sometimes be necessary to charge a battery in excess of 150 percent of rated ampere-hour capacity so that it can pass the capacity test.

When using the constant current method of charging, the battery is usually charged in two steps by using the START rate of current and the FINISH rate of current. (Lower starting rates may be used if required by such factors as equipment limitations.) These rates are usually given on the battery nameplates. A battery is charged at the START rate until the battery begins to gas or there is a sharp rise in temperature. The FINISH rate is then used to complete the charge to 150 percent capacity.

As an example, consider a 20-ampere-hour, 24-volt battery which has a 150 percent capacity of 30-ampere-hours. The START ampere rating as labeled on the battery is 8 amperes and the FINISH rating is 2 amperes. The battery is placed on constant current charge at 8 amperes for 2 hours before it starts to gas. The battery has been charged to 16 ampere-hours and must be charged an additional 14 ampere-hours. The charging current should then be reduced to 2 amperes and charged for 7 hours. If the battery temperature exceeds 15° F above charging room temperature *or* reaches 115° F, discontinue charging until the battery cools. A rise in temperature indicates that the battery is nearing full charge.

While the battery is being charged, the charging current should be kept constant at the rate being used. If the battery charger is not a self-regulating type, this operation can be achieved by manually adjusting the charger on a periodic basis.

During the finish charge, the individual cell voltages should be measured with a precision voltmeter to determine if all cells are rising evenly. Should some cells indicate a voltage lower than the others by 0.05 volt or more, it is advisable to leave the battery on charge a while longer for additional equalization. Do not allow the battery to overheat.

Constant Potential Charging

The charging voltage is usually set at 28.5 volts until the charging current drops below 3 amperes. Starting current may exceed 250 amperes, however, and may be limited by the charging equipment. A battery charged by this method generally will not deliver as much power as a battery that has been charged by the constant current method.

Automatic Battery Charger and Tester

An automatic battery charger and tester has been developed similar to the one discussed under the lead-acid battery. This tester also has three cycles of operation—a charge cycle, a discharge or test cycle, and a recharge cycle. (The constant current method is still preferred, however, if the equipment and men are available.)

Equalization Charging Procedure

When the battery is floated across a constant potential bus and subjected to operating conditions like those in an aircraft, an apparent loss of capacity results over a period of time. This loss is not a result of the battery aging, for the capacity of a nickel-cadmium battery does not decrease appreciably with age. Rather, the apparent loss of capacity normally results from cell imbalance, which occurs because of differences in individual cell self-discharge rates, charging efficiencies, and for other reasons.

When a battery fails to deliver its rated capacity during a capacity test, or when the cell voltages fail to equalize properly during charging, an equalization charge will usually correct the trouble. This charging may be achieved in the following manner:

1. Discharge the battery through a resistance that will permit current to flow at a 1-hour rate until battery terminal voltage reaches 18 volts (for a 19-cell 24-volt battery). For example, the resistance would be adjusted to allow 20 amperes of current to flow for a 20-ampere-hour battery.
2. When the battery voltage reaches 18 volts, adjust the resistance so that discharge current is reduced to the 5-hour rate, and continue discharging the battery. Short out individual cells as their voltage drops to approximately 0.25 volt.
3. When all cells have been discharged to 0.25 volt and shorted out, shorting devices should remain in place for a period of 8 hours or overnight.
4. After the shorting period, remove all shorting devices and recharge the battery by the constant current method.
5. After the battery is fully charged, allow it to stand for 3 hours or more and then check the electrolyte level of the cells. If required, adjust the level by adding distilled water and insure that the water is properly mixed with the electrolyte. The freezing point of properly mixed electrolyte is shown in table 5-2. Notice how the freezing point rises whenever the electrolyte varies either direction from the ideal mixture of 30 percent by weight, potassium hydroxide and water.

Table 5-2.—Freezing point of alkaline electrolyte

Percent potassium hydroxide	Specific gravity	Freezing point -°F-
25	1.239	-36°
30	1.290	-75°
35	1.344	-68°
40	1.399	-30°
45	1.456	+ 5°

Capacity Testing

Capacity tests should be performed after the initial charge and prior to installing the battery in the aircraft. They should also be performed each 100 flight hours (the frequency of tests may be varied after sufficient performance data are acquired to justify a change for particular battery applications), or for any of the following reasons:

1. The battery will not maintain voltage under load.
2. The battery uses an excessive amount of water.
3. The battery overheats.
4. Excessive corrosion appears on top of cells and hardware.

The capacity testing procedures described for a lead-acid battery will generally apply for a nickel-cadmium battery. Should a battery fail to pass the capacity test, it is advisable to discharge the battery as described under Equalization Charging Procedure above and recharge by the constant current method until the terminal voltage reaches 32 volts (for 19-cell 24-volt vented batteries). Insufficient charging or failure of cells to be properly equalized is the usual cause for the battery not passing the test.

Record capacity test data in a log book or on a form similar to that shown in figure 5-9.

SILVER-ZINC BATTERIES

The silver-zinc battery is maintained in the battery shop much the same as the nickel-cadmium battery. The state of charge is usually determined by the open circuit cell voltage. Each cell should read between 1.83 volts and 1.86 volts, which corresponds to a minimum terminal voltage of 25.6 volts.

If one or more cells read 1.60 volts or lower, while the others give higher readings, the battery has become unbalanced. The cause for this imbalance is usually an excessively high discharge rate. If this condition is left uncorrected, this imbalance on subsequent discharges will probably lead to cell reversal and battery failure. To correct this unbalanced condition, it is necessary to drain (discharge) the cells individually to 0 volts at a 10-ampere-hour or lower rate.

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The battery should then be recharged using a silver-zinc battery charger and the constant current method. The constant current method (charging at a 4-ampere rate) provides the quickest and best means of achieving and monitoring a normal input. In an emergency, a constant potential source may be used, with a rheostat connected in series to limit initial current surges to 50 amperes or less, providing the charge is monitored so as not to exceed 28 volts.

Servicing With Electrolyte

The silver-zinc battery is usually shipped in a dry condition. Only the special electrolyte furnished in the filling kit provided with each new battery should be used. Some battery types may use electrolytes containing special additives; other electrolytes, if used, may degrade the battery. The electrolyte must be kept in a closed alkali-resistant container, or it will absorb carbon-dioxide from the air and deteriorate. The filling kit contains detailed instructions for filling and should be followed in detail. If these instructions are not enclosed, refer to the applicable Maintenance Instructions Manual before attempting to fill a new battery. (NOTE: Batteries that will not be used within 30 days should be stored in the dry state.)

Silver-zinc batteries are sensitive to excessive voltage during charging and may be damaged if the voltage exceeds 2.05 volts per cell. Precaution must therefore be taken to insure that the charging equipment is adjusted accurately to cut off the current at 28.7 volts.

Where charging is not monitored automatically or periodically, a voltage cutoff system must be used which will interrupt the charging current when the voltage rises to 28.7 volts.

If possible charging should be performed at an ambient temperature of 60° to 80° F, and the battery temperature during charging should not exceed 150° F as measured at the intercell connections.

While silver-zinc batteries do not generate any harmful gases during normal charge and discharge operations, they do generate both oxygen and hydrogen gasses during excessive overcharging. All vent caps and sponge-rubber plugs must be removed from the vent hole during charging operations. If electrolyte is forced from the vent holes or if excessive gassing is evident, it is an indication of overheating, and the charging should be interrupted for 8 hours to allow the battery to cool. After charging, the batteries should be allowed to stand idle at least 8 hours.

The electrolyte level of the batteries should be adjusted periodically. The level in each cell of the battery is adjusted by either removing excess electrolyte or adding distilled water. Refer to the Maintenance Instructions Manual for the applicable aircraft for the proper electrolyte leveling procedures.

The safety precautions relating to silver-zinc batteries are the same as those which have been presented for the nickel-cadmium batteries.

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CHAPTER 6

AIRCRAFT ELECTRICAL POWER SOURCES

One of the first uses of electric power in aircraft occurred in 1915 when a standard shipboard radio set with a battery power supply was first installed in an aircraft. By the beginning of World War I, it had been determined that airborne radio was practical and installations were made in aircraft, using 45-volt dry cell batteries and 6-volt storage batteries.

Energy for the operation of most electrically operated equipment in modern aircraft depends upon electrical energy supplied by either d-c generators or a-c generators, or both. A generator is a machine that converts mechanical energy into electrical energy by electromagnetic induction. A generator which produces alternating-current energy is sometimes called an alternator. In most cases, however, as in this text, an alternator will be referred to as an a-c generator. A generator that produces direct-current energy is called a d-c generator. Either type, however, operates by the induction of an a-c voltage in coils as a result of varying the amount and direction of the magnetic flux threading through the coils. The major difference between an a-c generator and a d-c generator is in the method by which the electrical energy is collected and applied to the external circuit. For a detailed discussion of a-c and d-c generator theory refer to Basic Electricity, NavPers 10086-B.

The d-c generator is the regular source of electrical energy in some operational aircraft. One or more d-c generators driven by the engine in the aircraft supply electrical energy for the operation of all d-c equipment in the electrical system and energy for charging the battery. The number of generators is determined by the power requirement of a particular aircraft. In most aircraft, there is only one generator driven by each engine. (This is not to imply that each engine has a generator.) In some large aircraft, there are two generators on a single engine.

The 120/208-volt, 400-hertz, a-c power system has many advantages over the 28-volt d-c system. Due to higher voltage and a 4-wire (grounded neutral) system, the current carried in each wire is only a fraction of that required for the same power in a 28-volt d-c system. This permits the use of much smaller aircraft wiring with a great saving in weight. The a-c generator itself, especially in the larger sizes, and many of the system control and protection components are lighter. While 12 kilowatts appears to be the practical limit to the size of a d-c generator that can be successfully mounted on an aircraft engine, 60-kilovolt-ampere a-c generators are being used and even larger sizes seem practical. Service difficulties, such as high altitude commutation problems and brush wear, are greatly reduced in a-c generators. The types of a-c generators now under development completely eliminate brushes. The single-phase a-c generator, used extensively in the past, has advantages over the d-c generator and is still used to some extent today.

D-C GENERATORS

Generators used in naval aircraft differ somewhat in design because they are built by various manufacturers. All, however, have the same general construction and operate similarly. Figure 6-1 shows a d-c generator used on a typical Navy aircraft.

The most common aircraft d-c generator is the 28-volt shunt type machine; that is, the field windings are connected in parallel with the armature. High-output generators also employ

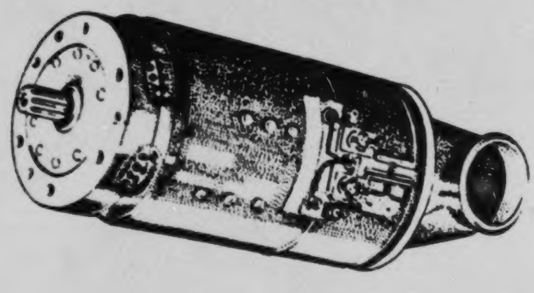

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Figure 6-1.—Typical d-c generator.

commutating poles (interpoles) and compensating windings. These are employed to minimize brush sparking and communication interference by counteracting the self-induced emf in the coil undergoing commutation and by opposing field distortion due to armature reaction. The magnetic field from these windings does not add to that produced by the shunt-field winding for producing output voltage; thus, these generators are not classified as compound generators.

CURRENT RANGE

Shunt generators for aircraft are designed for a wide range of current capacities. Generators used on basic type training aircraft and light observation and reconnaissance aircraft, which have a minimum of electrical equipment, sometimes use generators rated as low as 50 amperes. Large attack aircraft, patrol aircraft, and transports use generators rated as high as 500 amperes. Some types of aircraft contain so much electrical equipment that they require more than one generator in order to supply enough current for the load. It is not uncommon to find two or more shunt generators mounted on one aircraft.

The use of more than one generator on an aircraft provides a safety factor. Should one generator become inoperative the electrical system will still have a source of generator power. In the multigenerator aircraft the normal electrical demands are such that the generators are loaded considerably below their maximum capacity. This allows near-normal operation in the event one of the generators fails since the others can absorb the load and still not be overloaded.

SPEED RANGE

Aircraft generators are designed to operate within two different speed ranges. The speed range is that range of speed in which a generator must be operated in order to obtain rated generator output; that is, rated voltage at all values of load current with the current range of the generator. The low-speed range is approximately 2,000 to 4,500 rpm and the high-speed range is approximately 3,000 to 8,000 rpm. Either end of these ranges may vary slightly, depending on the design of a particular generator. Some generators are designed to operate at an upper speed range as high as 10,000 rpm.

A–C GENERATORS

The use of the a-c power system has resulted in better design and utilization of equipment. Typical electronic equipment, powered from d-c power, may have an inverter as an integral component for supplying a-c power and a dynamotor for supplying higher voltage d-c power. These components are very heavy for their relative power outputs as well as being sources of unreliability and increased maintenance. The same a-c powered electronic equipment could obtain various a-c voltages and d-c power by the use of simple transformers and transformer-rectifiers, respectively. These components are light-weight, simple, reliable devices. For the past several years, nearly all the new aircraft designs have included a-c primary power systems.

As total aircraft power requirements continue to grow, and as the majority of aircraft equipment is converted to a-c power, it can be seen that the predominant power system for naval aircraft is 3-phase, 120/208-volt, a-c. The factors which determine the frequency of the voltage produced by a generator are the number of magnetic poles in the machine and the rate of rotor rotation. With the number of poles a fixed quantity, constant frequency requires constant rotor speed.

PRIME MOVERS

The device, such as an aircraft engine, that provides the driving force for a generator, is called the prime mover. Early attempts were made to control the rotor speed of a-c generators by the use of variable-pitch propellers or slipping clutches. Due to the unsuitability of these early methods, most a-c generator power was of variable frequency; that is, it was generated by an a-c generator directly driven by a reciprocating engine. This usually gave approximately a 2 to 1 speed range from maximum engine power to minimum cruise, and the engine gear ratio was chosen to give power from 400 to 800 hertz. However, ground idle speed of the engine was usually considerably below that required to obtain 400 hertz, and no usable power could be taken from these generators on the ground.

It became apparent that great weight savings and vastly improved performance could be effected in utilization of equipment if power could be supplied at an essentially constant frequency. As the total power requirements grew, the point was reached, from a weight and performance standpoint, where it was more advantageous to furnish the a-c power at a constant frequency. The constant frequency is obtained by a hydromechanical constant-speed drive which converts the variable engine speed to a constant speed output to drive the generator. A constant speed can also be obtained by the use of an air or gas turbine generator drive or by the constant rpm of a turboprop engine. The air or gas turbine may obtain its air supply by using bleed air from the jet engine compressor or from a separate compressor.

The hydromechanical drive will hold the frequency steady within a few hertz of the desired 400, and load and fault transients are held approximately within a 380- to 420-hertz range. Air or gas turbine drives are somewhat smoother in operation and hold steady-state frequencies within ±10 hertz.

The constant-speed characteristic of the turboprop engine insures good frequency stability of the a-c generator output. Frequency stability is maintained within very close limits through control of engine speed by the propeller synchrophaser system which holds the rpm constant and the a-c generator frequency to 400 ±0.8 hertz. Should the synchrophaser fail, the propeller-governing mechanical-hydraulic system will hold the generator frequency to 400 ±4 hertz.

TYPES OF A-C GENERATORS

The many types of a-c generators used on Navy aircraft range in size from the relatively tiny tachometer instrument generator to the 60,000 volt-ampere machines used on multi-engine aircraft. Regardless of weight, shape, or rating, practically all of these generators have the following characteristics in common:

1. The a-c output is taken from a set of stationary windings (stator).
2. The a-c generator field (rotor) is a rotating magnetic field with fixed polarity.
3. Where voltage control is used, it is accomplished by controlling the strength of the rotating magnetic field.
4. The frequency of the output voltage is controlled by regulating the speed of rotation of the rotating magnetic field.

Single-Phase A-C Generator

The single-phase type a-c generator is finding less application in aircraft that demand large amounts of a-c power. However, it is used in aircraft such as trainers and some fighters. Due to the smaller power demands of both the a-c and d-c systems of these aircraft, usually one generator is used to provide both alternating and direct current. These are known as a-c/d-c or double-voltage generators. A-c/d-c generators will be discussed later in this chapter.

Three-Phase A-C Generator

Present military specifications require that the basic aircraft a-c power system produce voltage with a value of 120 and 208 volts. A 3-phase generator is actually three separate power sources enclosed in one housing (fig. 6-2 (A)). In order to produce the required 120/208-volt output, external connections must be made to form a wye as shown in figure 6-2 (B). Each output winding will produce 120 volts as measured from n to a, b, or c. If two separate phase voltages are measured together (a to b, a to c, or b to c) then the voltage output will be 1.73 times the single-phase voltage (208 volts).

In the 4-wire grounded neutral, wye connected system, as applied to aircraft, the neutral wire is connected to the frame of the aircraft, which in this case constitutes ground. The 3-phase wires are then connected to buses from which power is taken to supply the various loads. Those loads operated line-to-neutral are connected between one of the buses and the aircraft frame. Those operated line-to-line are connected between two of the buses.

The line-to-line voltage found in a 3-phase, wye-connected system is the vector sum of the voltages generated by two separate phase windings. Because a phase difference of 120 degrees exists between the two generated voltages, they reach their peak amplitudes at different times and consequently must be added vectorially, not directly.

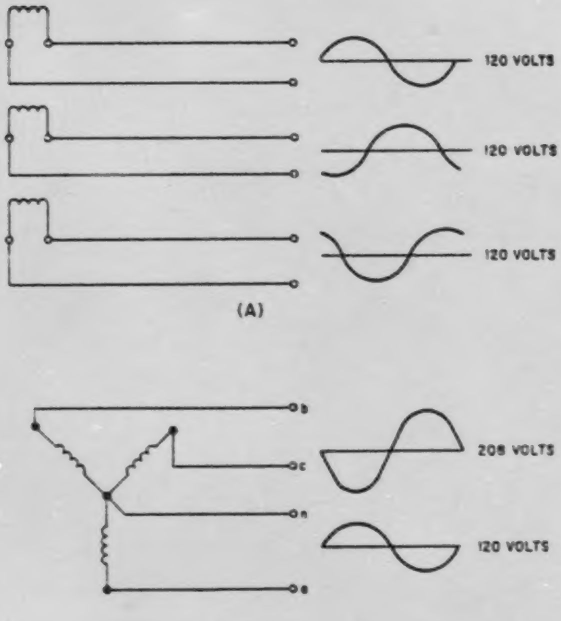

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Figure 6-2.—Three-phase a-c generator output.

BRUSH TYPE.—Figure 6-3 shows a brush-type 3-phase a-c generator. This a-c generator is an engine-driven, wide speed range, variable-frequency power supply. It provides 30-kilovolt-amperes (kva) of 3-phase power at 120/208 volts, 400/800 hertz at a 90 percent minimum lagging power factor, when rotated from 4,000 to 8,000 rpm.

Figure 6-4 shows the internal wiring of this a-c generator. It contains a separate d-c generator called an exciter. The exciter output is controlled by an external voltage regulator which varies the resistance in series with the exciter shunt field winding. The exciter output is also routed through sliprings to the a-c generator field windings. The magnitude of the d-c voltage passing through the field windings determines the strength of the magnetic field and thus the voltage of the a-c generator.

Figure 6-5 is a disassembled view of the main assembly of an a-c generator. It shows those items which are of importance to operating personnel.

The collector rings, exciter armature, rotating field, and a fan are mounted on the same shaft

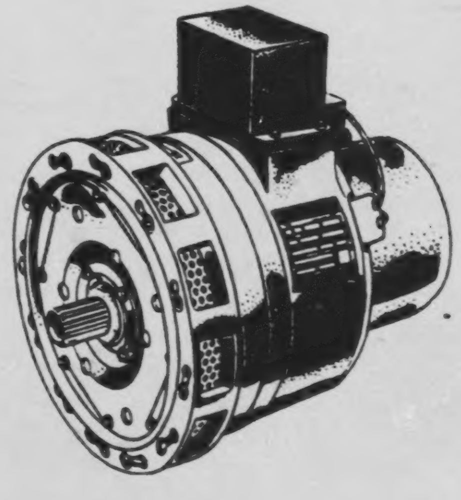

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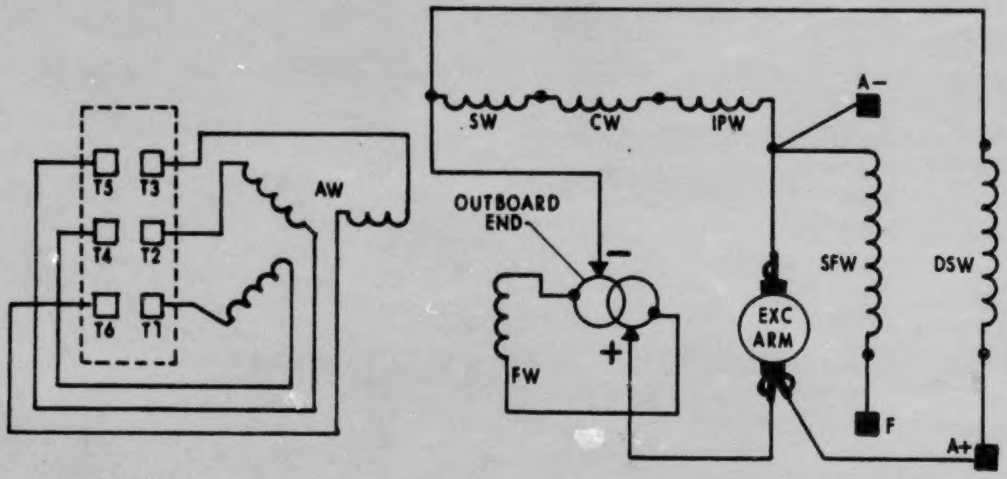
Figure 6-3.—Brush-type 3-phase generator.



SFW-exciter shunt field winding.
AW-a-c generator armature winding.
FW-a-c generator field winding.
SW-exciter series winding.
CW-exciter compensating winding.
IPW-exciter interpole winding.
DSW-exciter differential shunt winding.

AE.124

Figure 6-4.–Internal wiring diagram of brush-type a-c generator.

which is supported between two bearings. This shaft is driven by a flexible drive spindle which mates directly in the engine-drive spline. A friction damper is incorporated to damp twisting oscillations, thereby reducing spline wear and preventing spindle breakage. The fan provides ventilating air while the aircraft is on the ground and there is no ram air pressure. This gives sufficient cooling for the generator to deliver power at a 25 percent rated load (maximum) continuously.

The stationary member of the generator is made up of the a-c armature and the d-c exciter field. Both a-c and exciter terminal boards are mounted so that they are easily accessible. All brush rigging is located on the generator and is protected with a brush cover. Slotted-hole type mounting provides for ease in attaching to the engine pad. Capacitors connected between the exciter armature terminals and ground suppress radio noise.

The a-c generator rotating field has 12 poles with adjacent poles being of opposite polarity. One cycle per revolution is produced by each pair of poles; thus, 6 cycles are produced per revolution. The output frequency of the generator varies in direct proportion to the engine drive speed. A generator operating at 6,000 rpm is operating at 100 revolutions per second or at 600 hertz.

BRUSHLESS TYPE.–Most of the modern aircraft are using a new concept in voltage generation. This concept eliminates the need for brushes in the a-c generator. The advantage of a brushless generator over a brush type is its increased reliability and a greater operating time between overhaul, principally because there are no brushes or sliprings to wear and contaminate the segments as in a brush-type generator. Figure 6-6 is a disassembled view of the main assembly of a brushless generator. It shows those items which are of importance to operating personnel.

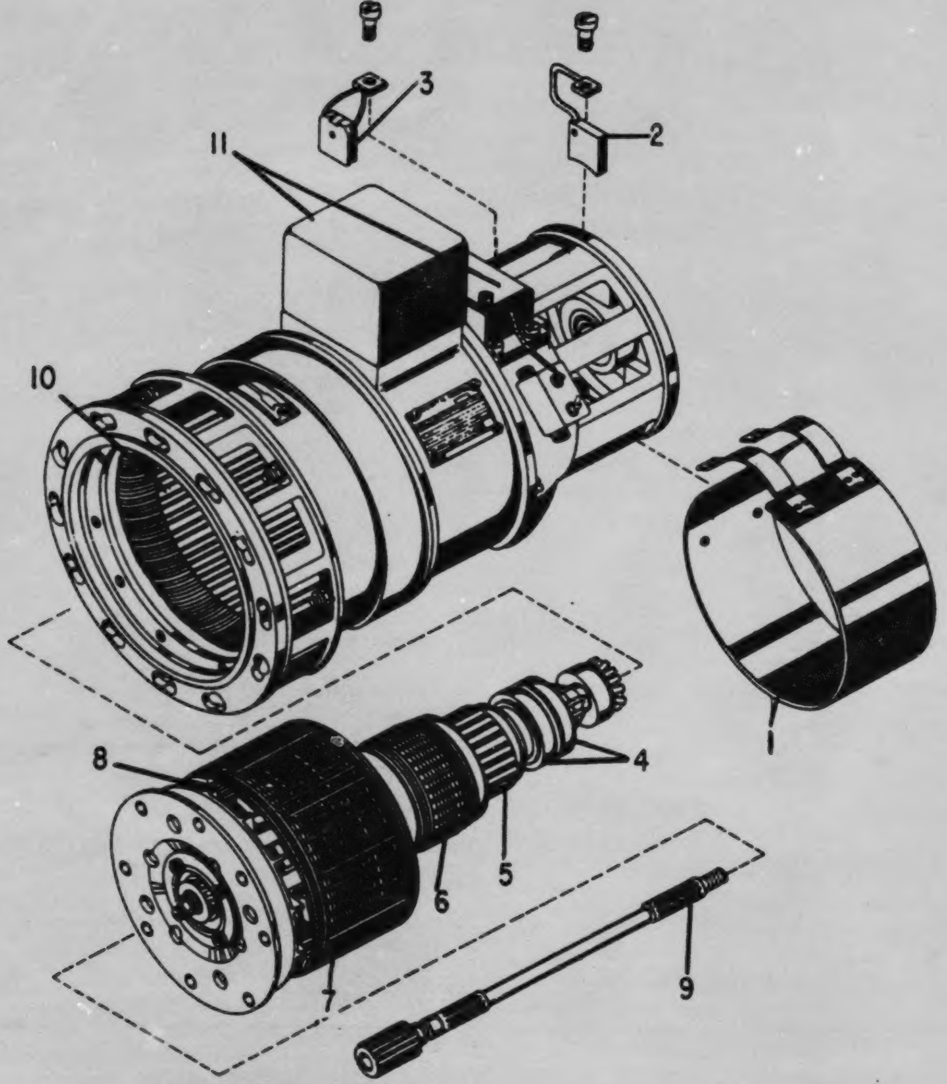


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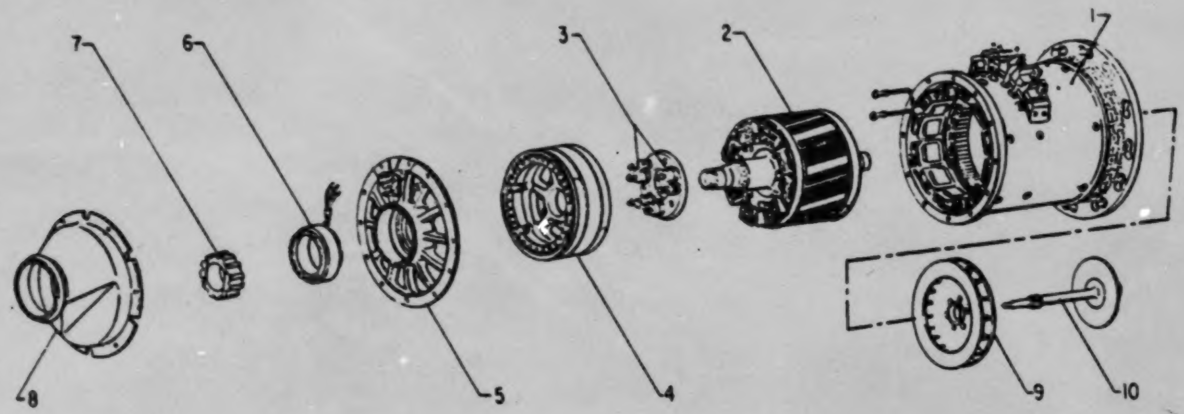
Figure 6-5.—Disassembled aircraft brush-type a-c generator.

The brushless generator shown in figure 6-6 is a salient 8-pole, 6,000 rpm a-c generator with a 12-pole a-c exciter and a three-phase, half-wave diode rectifier assembly mounted to rotate with the exciter armature and main alternator field assembly. The exciter rotor consists of a hollow frame assembly with the main a-c field mounted on the inside of the assembly and connected to a common drive shaft. A single-phase permanent magnet generator (PMG), assembled with the exciter rotor, furnishes control voltage and power for the voltage regulator. Three rectifiers are mounted on the exciter rotor and connected to the



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1. Stator assembly.
2. Rotor and shaft.
3. Rotating diode assembly.
4. Exciter rotor.
5. End bell.
6. PM generator stator.
7. Permanent magnetic rotor core.
8. Generator to air duct adapter.
9. Fan assembly.
10. Drive shaft assembly.

Figure 6-6.–Disassembled brushless a-c generator.

exciter armature windings. The engine reduction gearing is protected from possible damage, if the generator should seize, by a shear section that is incorporated in the generator stub shaft. A cooling air fan mounted at the drive end of the generator provides an airflow around the rotor and stator windings and also through the hollow shaft (on which all rotating components are mounted) to provide a flow of air to the drive and bearings.

Some aircraft have generators that are cooled by oil. The oil enters the generator through an inlet port and leaves through an exit port located in the mounting flange of the generator. As the oil passes through the generator, it absorbs the heat from the rotor and stator. At the same time, it cools the rotating seals and lubricates and cools the bearings. Aircraft engine oil is used for cooling the generator and also for operating the constant speed drive.

As the generator starts to rotate, (fig. 6-7) the permanent magnet generator (PMG) starts supplying single-phase a-c voltage to the voltage regulator and other protective circuits. The PMG power is rectified and supplied to the exciter field, and the resulting electromagnetic field, built up by the excitation current flowing in the exciter stator, induces current flow in the rotating 3-phase exciter rotor. This current is half-wave rectified by the shaft-mounted rotating rectifiers, and the resultant direct current is applied to the rotating field winding of the 3-phase a-c generator. The rotating electromagnetic field induces an a-c voltage in each leg of the 3-phase, wye-connected output winding of the generator stator. Voltage regulation is accomplished by varying the strength of the exciter stationary field. By using an integral a-c exciter, the necessity for brushes within the generator is removed and minimization of radio noise is accomplished by the absence of brushes.

Protection against the shorting of any feeder line between the generator and the bus it powers (called feeder fault) is provided by two 3-phase differential transformers. One transformer is mounted on the generator as shown in figure 6-7, and its coils sense the current flow through each of the legs that connect the ground side of the generator stator to ground. The other transformer is located at the main buses and

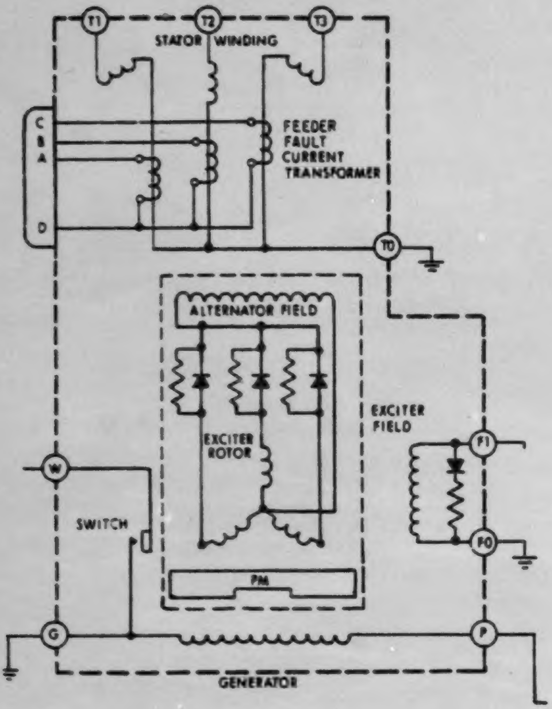

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Figure 6-7.—Sectional schematic of a brushless a-c generator.

senses current flow through the three feeder lines. Should a short occur in the feeder line, a difference in current flow between the two transformers will be detected by a sensing circuit and remove the generator from the line.

A generator mechanical failure warning device is incorporated in the generator. It consists of a soft copper strip embedded in and insulated from the generator stator assembly. Should a bearing begin to fail, increased bearing clearance allows the rotor to rub against the stator, thus wiping the copper strip across the insulation and completing a warning light circuit to ground.

A-C/D-C GENERATORS

Most modern aircraft now utilize a-c electrical equipment. This necessitates having a source of alternating current. On aircraft that require a large capacity of a-c power, separate a-c generators are used. On aircraft that require only a small amount of a-c power, rather than have two separate generators, the two generators are combined in one housing. This is known as a combination a-c/d-c generator. The direct-current rating of this type generator usually ranges from 25 to 200 amperes. These combination generators are designed either as low-speed or high-speed machines. The a-c section of this generator has already been discussed.

D-C EXCITERS FOR A-C GENERATORS

All generators, both d-c and a-c, need direct current to excite the field coils. In an a-c generator containing no d-c section capable of supplying an external d-c load, provisions must be made to supply the a-c generator with d-c excitation. This may be accomplished by providing a small d-c generator in the same housing with the a-c generator or by a small external d-c generator not in the same housing with the a-c generator. The new brushless type a-c generators use diodes to obtain the d-c voltage for the main rotor fields.

The external exciter may be mounted on one end of the a-c generator shaft, thereby being driven by the same prime mover which turns the a-c generator; or it may be mounted separately and driven by some other prime mover. In all cases, the purpose of the exciter is to supply excitation for the field windings of the a-c generator. The exciter generator is quite small in comparison to a regular generator, since the only load it supplies is its own field windings and the field windings of the a-c generator.

BASIS FOR D-C GENERATOR RATINGS

The speed range of a generator is governed by the output voltage desired. The speed at which the generator will have to turn to produce this particular output voltage depends on its electrical design. Since power is equal to E times I, the power rating of a generator is determined by the voltage of the generator times the current capacity. The current capacity of a generator is determined by the size of the armature conductor, the type of winding on the armature, and the efficiency of the generator cooling system. Power rating is expressed as continuous or overload.

The continuous rating is the amount of power (current) which the generator can deliver indefinitely with proper cooling without injury to the generator. The overload rating is the amount of power which the generator can deliver for short periods of time. This overload rating is usually expressed as a percentage of the continuous rating and time is expressed in minutes. EXAMPLE: 150 percent for 2 minutes in regards to a generator rated at 200 amps would mean that 300 amps of current could safely be drawn from the generator for a period of 2 minutes.

The continuous duty rating of high-speed engine-driven generators is given for a speed of 6,000 rpm. Sustained operation at higher speeds requires derating (decreased output).

Factors Affecting Generator Power Ratings

A high-speed generator can produce more power for a given size than a low-speed machine. This is possible since less wire in series is necessary in producing a given voltage in the high-speed generator. Since a shorter length of wire is necessary, a larger size wire can be used, thus increasing the current capacity of the generator.

Due to the large amounts of current which aircraft generators deliver, cooling becomes a major problem. Aircraft generators are sometimes cooled by blast air directed through the generator. The higher the altitude at which the aircraft is operating, the more difficult it is to cool the generator because of the rarefied condition of the atmosphere at high altitudes. The amount of heat which a given volume of air can remove from a generator is determined by the density of the air; the less the density, the less heat removed. If the temperature of the generator is allowed to rise too high, the insulation may be damaged.

The voltage, current rating, and speed range of aircraft generators are usually found on a metal nameplate secured to the generator frame. If this information cannot be found on the generator, it can be found in the manufacturer's manual or the NavAir publication for that particular generator.

Figure 6-8 shows a cutaway view of a typical a-c/d-c generator. The a-c section is a single-phase a-c generator; thus, the operation of this generator is similar to an ordinary single-phase a-c generator. The major difference is that instead of a small d-c generator (exciter) which would provide only the field current for the a-c generator section, the d-c section is capable of providing considerable d-c output. Thus, this type generator also provides d-c power for the aircraft's d-c loads.

The generator shown in figure 6-8 is similar to those described earlier insofar as mounting, driving, and cooling are concerned. The d-c section is a standard d-c generator, with rotating armature and commutator, stationary brushes, stationary shunt field, compensating field, and commutating field. It is designed to work with the shunt field controlled by a voltage regulator. The d-c sections of two generators may be operated in parallel.

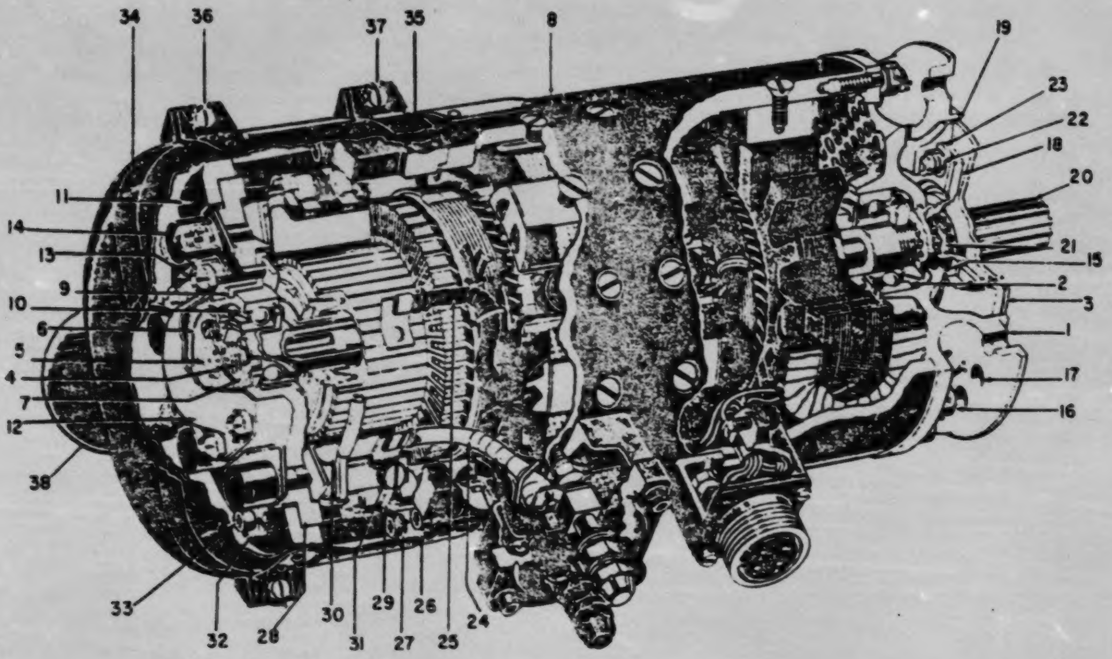
The a-c section is an inductor a-c generator, with a 12-projection rotor, stationary armature, and stationary field. It is designed to operate individually with an external capacitor in the armature circuit and with the field controlled by a voltage regulator. They cannot be operated in parallel.

It is a high-speed generator (4,400/8,000 rpm) with a d-c output of 6 kilowatts (30 volts at 200 amperes). The d-c shunt-field current is 8 amperes at full load.

The a-c section of the generator provides 1.2 kva of variable-frequency (800/1,600 hertz) power at 120 volts. The maximum field current of the a-c section is 3.3 amperes.

EMERGENCY ELECTRICAL POWER

For many years the storage battery was considered the only source of emergency electrical power. However, the many recent advancements in avionics equipment and the sophistication of our modern aircraft have caused emergency electrical loads to exceed the capability of



AE. 119

1. Mounting flange.
2. Drive-end bearing.
3. Vibration damper.
4. Outer shaft.
5. Inner shaft.
6. Retaining washer.
7. Beveled nut.
8. Field frame.
9. Brush rigging insert.
10. Commutator-end bearing.
11. End shield.
12. Oil seal cap.
13. Positioning screw.
14. Castle nut.
15. Grease seal.
16. Mounting flange screw.
17. Mounting hole.
18. Vibration damper disk, inner.
19. Vibration damper disk, outer.
20. Drive-end shaft extension.
21. Vibration damper washer.
22. Vibration damper spring.
23. Vibration damper plate.
24. Positive B lead.
25. Negative field lead.
26. Plate.
27. End shield screw.
28. Brush holder yoke and bearing support.
29. Brush terminal.
30. Brush holder.
31. Brush terminal screw.
32. Clamp.
33. Brush rigging screw.
34. Airblast cover.
35. Clamping ring.
36. Airblast cover screw.
37. Clamping ring screw.
38. Cooling air inlet.

Figure 6-8.—Cutaway view of a-c/d-c generator.

ordinary storage batteries. Also, the aircraft storage battery with its highly corrosive electrolyte does not readily lend itself to the precision equipment and precious metals used in today's aircraft. For these reasons, new methods of providing emergency electrical power have been developed.

EMERGENCY POWER GENERATORS

Many late-model jet aircraft are equipped with ram-air emergency generators. These provide emergency electrical power in the event of main electrical power failure. Some of these are d-c generators and some are a-c generators; a-c

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systems utilize rectifiers for the d.c. that is required by the aircraft. Different types of emergency power generating systems have been developed, and the manner in which they are installed depends upon the type of aircraft.

In a typical installation the emergency electrical power is provided by a power package which, when used, is positioned outside the aircraft. This occurs when the pilot operates a lever which, through a linkage, pneumatically, or by a spring arrangement, causes the power package to protrude. The ram-air of flight, which is caused by the aircraft moving through the atmosphere, provides the turning power for the turbine which, in turn, rotates the generator's armature.

The systems are constructed so that the emergency generator will not be placed on the line until its armature is up to speed. This is controlled in different ways; for example, on the F-8 aircraft the pilot places the generator on the line by throwing a switch. He throws this switch after an indicator light comes on, which indicates that the generator output is up to minimum standards. In the F-4 aircraft the emergency generator is automatically placed on the line by an air-pressure actuated switch. This switch connects the output of the emergency generator to the solenoid of a relay which energizes when the generator is up to speed. When the relay energizes, it connects the generator to the bus. The aircraft must have an airspeed of at least 190 knots before this switch actuates.

A typical 3-phase emergency generator is shown in figure 6-9 (A). This generator has a capacity of 3 kva, a voltage output of 120/208 volts at 400 ±20 hertz, and the output windings are wye connected. The frequency of the output voltage is maintained by automatic positioning of the variable-pitch blades (fig. 6-9 (B)) and speed regulating section of the ram-air turbine.

Ground testing of some types of emergency generators may be performed while the generator is mounted on the aircraft. When this is done, compressed air from a gas-turbine compressor is funneled onto the turbine blades to drive the generator.

AIRBORNE AUXILIARY POWER UNITS

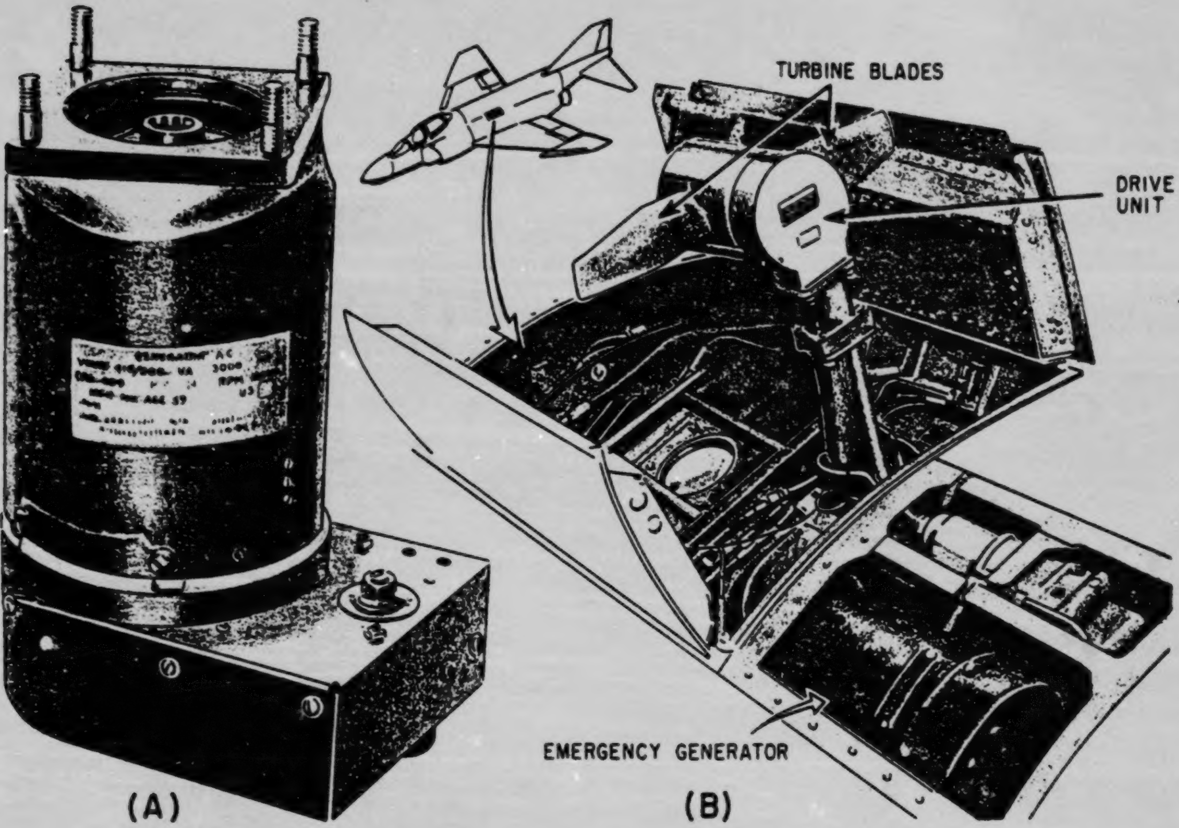
Some of the larger aircraft are equipped with auxiliary power units (APU). These may be installed at different locations on different aircraft. They are used to furnish electrical power when engine-driven generators are not operating, when external power is not available, or when the engine-driven generator fails.

The APU is utilized to furnish power since excessive battery usage must be avoided when possible. The power output from the APU provides a constant voltage at a constant frequency, which is advantageous since the APU is not dependent on aircraft engine rpm.

Some of these units use a gasoline engine to drive the generator, while others use a gas turbine. The gas turbine type also provides compressed air to start engines, using the pneumatic starting system, and for air conditioning, thereby making the aircraft independent of the need of ground power units to carry out its mission. There are many types and configurations of gas turbine units; however, because of their similarity in construction and operation, only one is described in the following paragraphs.

GTCP95 Unit

The gas turbine powerplant unit (hereafter referred to as APU) used on late aircraft is capable of furnishing electrical power, starting air, and air to heat or cool the interior of the aircraft while on the ground by providing a fresh air supply for the aircycle cooling systems. (See fig. 6-10.) The gas turbine engine of the APU is a self-contained power source which requires only the aircraft battery and fuel for starting. Shaft power at the main output drive pad is used to drive a generator. Pneumatic power is available as clean, compressed air at the output end of the engine bleed load control and air shutoff valve located at the rear right of the engine. The engine is basically composed of two main sections and four main systems. The two main sections include an accessory assembly located at the front of the engine, and a compressor and turbine assembly located at the rear. The four



AE.127

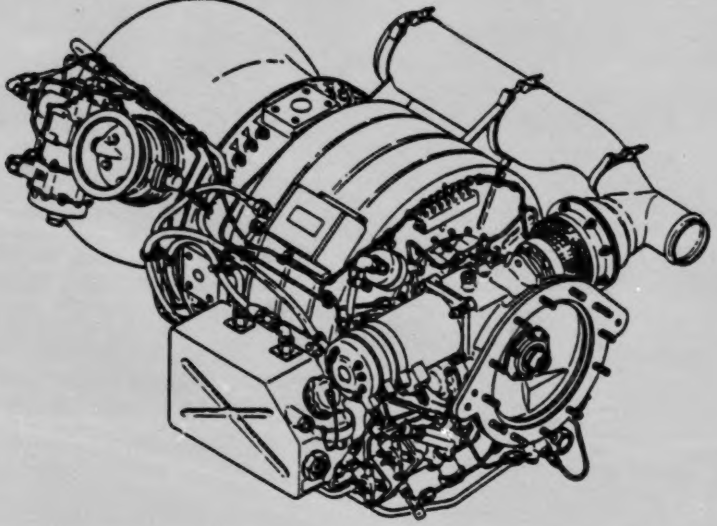
Figure 6-9.—(A) Emergency generator; (B) typical emergency generator installation.

main systems consist of an electrical system, a fuel control system, a bleed air system, and a lubrication system.

OPERATION.—The engine develops power by compressing ambient air with a two-stage centrifugal compressor. Compressed air, mixed with fuel and ignited, drives a radial inward flow turbine wheel. The rotating shaft of the turbine wheel drives the compressor, the accessories, and the output shaft for the a-c generator. Pneumatic power is obtained by bleeding air from the compressor before it is mixed with fuel.

GAS TURBINE ENGINE ELECTRICAL SYSTEM.—The electrical system (fig. 6-11) provides automatic actuation in proper sequence of the various circuits that control fuel supply, ignition, engine starting, acceleration, fuel flow, and monitoring. The electrical system consists of the following main components: holding relays, oil pressure switch, multiple centrifugal switch assembly, time totalizing meter (hourmeter), and harness assembly.

The ignition portion consists of an exciter and ignition plug controlled by the multiple centrifugal switch. Ignition is only required during



AE.156

Figure 6-10.–Gas turbine powerplant unit (GTCP-95).

starting and is automatically cut at approximately 95 percent engine rpm.

The switches and controls required for starting, stopping, monitoring, and loading circuits are located in the aircraft. These components include a master start-stop switch and a start relay. A pad is provided on the oil pump assembly housing for mounting the tachometer-generator.

CENTRIFUGAL SPEED SEQUENCE SWITCH.–This component (fig. 6-12) controls the sequence of operation of various electrical components. It is driven by the accessory drive idler gear shaft. The input drive shaft turns a knife-edged fulcrum (flyweight support) and a pair of flyweights pivot on the knife edges. Each flyweight has a toe which lies under the outer race of a ball bearing on the actuating shaft. As the centrifugal switch is turned, centrifugal force causes the flyweights to pivot on the knife edges, moving the actuating shaft to the right against the lever arm. Three electrical switches, not shown in the figure, are actuated at 35 percent, 95 percent and 106 percent of turbine speed by the lever arm. Fine adjustment of these switches can be accomplished by applying spring tension to the lever arm with the three adjustment screws shown in figure 6-12. The functions of the switches are:

1. 35 percent–turns off starter motor.
2. 95 percent–arms load control circuits, starts hourmeter, turns off ignition.
3. 106 percent–stops unit (overspeed protection).

As the input shaft is rotated, the flyweights (acted upon by centrifugal force) move outward, forcing the actuating shaft to move the lever arm, actuating the switches. Since the lowest percent speed adjustment spring acts on the lever arm during the actuating of all switches, a change in its setting will also affect the setting of the 95 percent and 106 percent switches. A drift in setting of the 106 percent switch will affect only the 106 percent switch.

Generally, checking an overspeed switch in a gas turbine requires that the unit be operated above its governed speed. However, the multiple

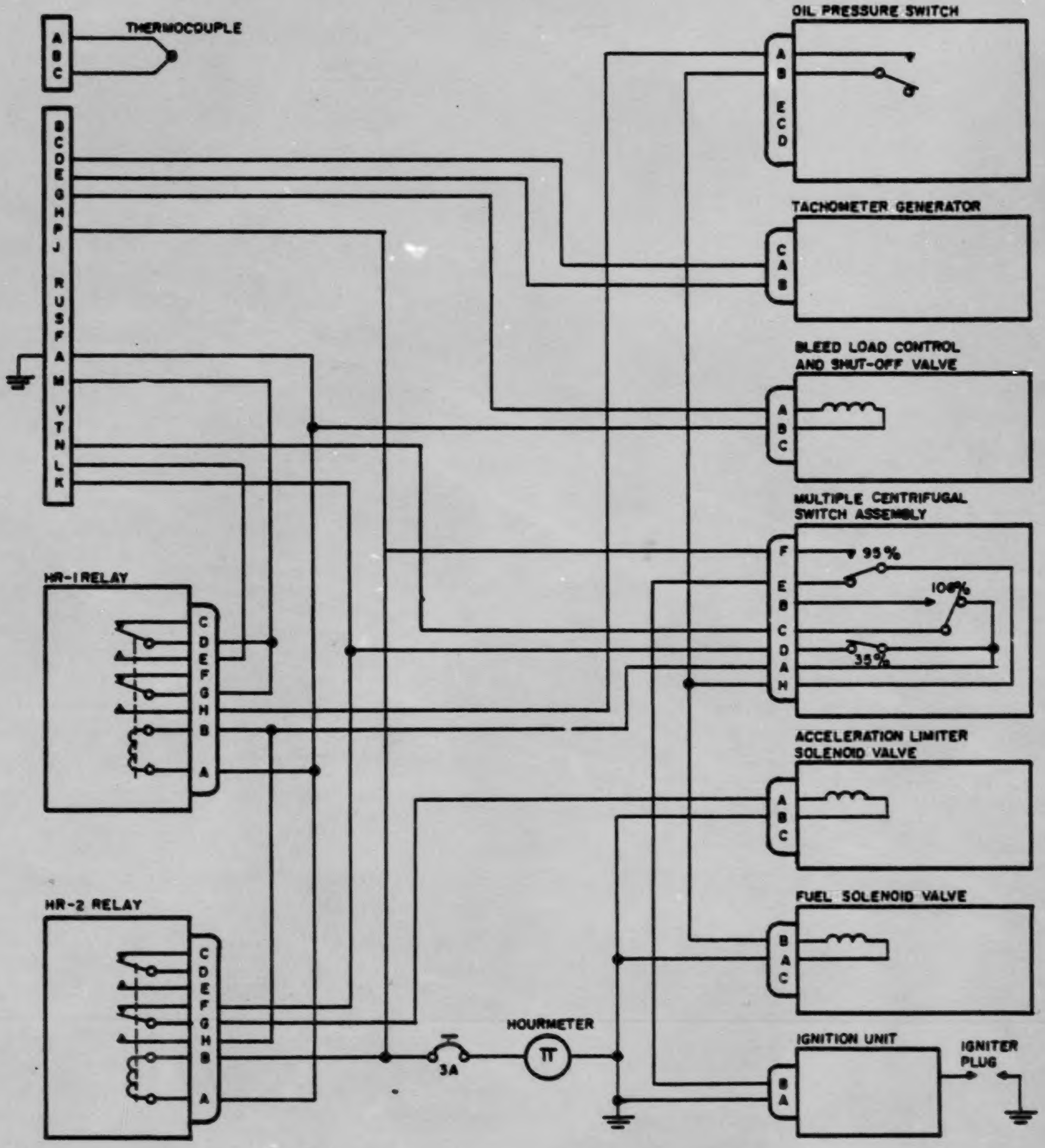
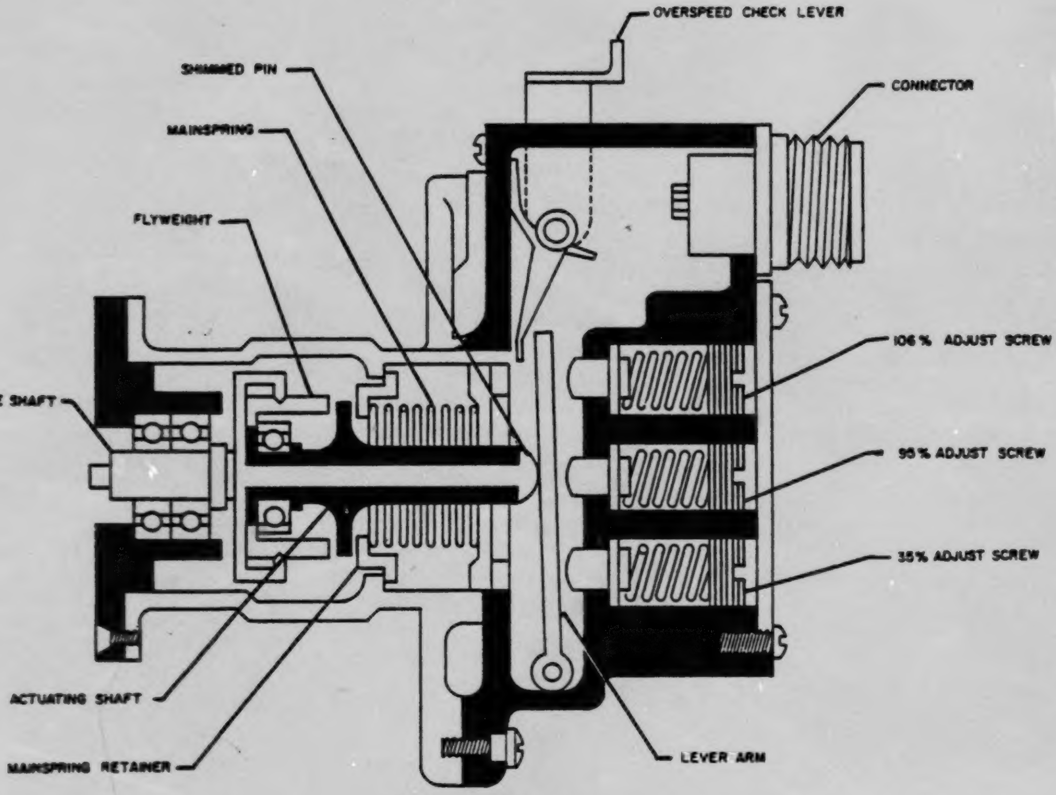

THERMOCOUPLE
A B C
B C D E G H P J R U S F A M V T N L K
OIL PRESSURE SWITCH
A B E C D
TACHOMETER GENERATOR
C A B
BLEED LOAD CONTROL AND SHUT-OFF VALVE
A B C
MULTIPLE CENTRIFUGAL SWITCH ASSEMBLY
F E B C D A H
95%
106%
35%
HR-1 RELAY
C D E F G H B A
ACCELERATION LIMITER SOLENOID VALVE
A B C
FUEL SOLENOID VALVE
B A C
HR-2 RELAY
C D E F G H B A
3A
HOURMETER
IGNITION UNIT
B A
IGNITER PLUG
AE.159

Figure 6-11.—GTCP-95-2 gas turbine engine electrical schematic.


OVERSPEED CHECK LEVER
SHIMMED PIN
CONNECTOR
MAINSPRING
FLYWEIGHT
106% ADJUST SCREW
DRIVE SHAFT
95% ADJUST SCREW
35% ADJUST SCREW
ACTUATING SHAFT
MAINSPRING RETAINER
LEVER ARM

AE.160

Figure 6-12.–Centrifugal switch assembly.

centrifugal switch assembly on the engine incorporates a lever, which extends from the switch housing, that can be manually positioned to actuate the three switches. The lever is spring loaded in order not to interfere during normal operation. When the lever is manually actuated, it rotates on a pivot, forcing the centrifugal switch lever arm to actuate the switches. This check may be performed with the unit operating or stopped. Actuation of the switch will cut off the fuel flow to the combustor and stop the unit.

STARTER MOTOR.–The starter provides the initial power for rotating the components of the gas turbine to self-sustaining speeds. It rotates the compressor to a speed high enough for correct airflow for combustion, and continues to assist the unit to accelerate after light-off to prevent excessive turbine temperature at low speeds.

The starter motor is rated approximately 1.5 hp at 14 volts at 5,000 rpm. The starter has a duty cycle of 1 minute ON and 4 minutes OFF.

The starter motor armature shaft is splined and pinned to the clutch assembly. The starter clutch assembly performs two functions. As a friction clutch, it prevents excessive torque between the starter and accessory drive gears to protect both. As an overrunning clutch, it provides the means of automatically engaging the starter with the gear train for starting, and automatically disengaging it when the unit has reached a condition allowing it to accelerate and run without assistance.

The friction clutch section provides overtorque protection. The assembly is set to slip at approximately 135- to 145-pound-inches of torque. Due to the inertia the engine offers when the starter motor pawls first engage with the gearbox ratchet, the overrunning clutch flange and splined clutch plates tend to remain stationary while the motor, the clutch housing, and the keyed clutch plates rotate. Slippage occurs until engine and starter speeds have increased enough to develop less than the specified torque value.

The starter is normally deenergized by the centrifugal switch at 35 percent. If the switch does not cut out at this speed, the starter may fail from overheating, or it may fail mechanically from overspeed. If the overrunning clutch does not disengage properly, mechanical overspeed failure of the starter will result.

TRANSFORMERS

A transformer, by itself, cannot be considered a true electrical power source. A true electrical power source must be capable of producing electrical energy from some other type of energy, such as chemical or mechanical. However, the transformer does take electrical energy in the form of an a-c voltage and converts it to a different usable a-c voltage. The construction and theory of operation of transformers are covered in Basic Electricity, NavPers 10086-B.

TRANSFORMER-RECTIFIER

As discussed earlier in this chapter, manufacturers of recent Navy aircraft have chosen to exclude storage batteries from aircraft design. A-c powered equipment has been proven to be far more efficient than the larger, heavier d-c powered equipment, so the d-c generator has been virtually replaced by the a-c generator; therefore, a source of d-c power must be provided for such functions as lighting and for control of a-c powered equipment. The most common device now used to provide the necessary d-c voltage is the transformer-rectifier (TR).

Transformer-rectifiers employ no moving parts, other than a cooling fan, which provides high reliability and ruggedness unmatched by most other avionics equipment. A separate voltage regulator is not required so long as the a-c input voltage can be maintained within reasonable limits. Current capability is generally high and is largely dependent on the cooling provided.

Figure 6-13 shows an electrical schematic of a typical transformer-rectifier. It requires 120/208-volt, 3-phase, 4-wire input at 400 hertz. It has an output capability of 200 amperes at 25.5 to 29.5 volts.

The input a-c voltage is applied through pins B, F, and I, through a radiofrequency (RF) filter which is used to reduce noise interference to other avionics equipment in the aircraft, to the wye-connected primary of a stepdown power transformer. The a-c output of the wye delta-connected secondaries is rectified by diodes CR1 through CR12, sent through interphase transformer T2, and then through a filter network consisting of L2, C4, and C5 to the load. Interphase transformer T2 has an adjustable center tap which may be set to balance the two delta transformers for equal current output. The filter network reduces the 4800-hertz ripple voltage to nearly straight-line d-c voltage.

Fan motor B1 is connected in parallel with the power transformer primary. This fan motor is highly essential to proper operation and provides the only moving parts of the transformer-rectifier. A thermostat (S1) is provided to detect excessively high temperatures and, in conjunction with external circuits, can turn on an overheat warning light, automatically disconnect the input, or perform both functions.

AUTOTRANSFORMER

The autotransformer is similar in most respects to an ordinary transformer except that it has only one winding which is common to both primary and secondary. Within the limits of its application, it offers savings in both size and cost over conventional units. These savings are greatest when the turns ratio is less than 2 to 1 (either step-up or stepdown), and diminish to insignificance when the turns ratio increases

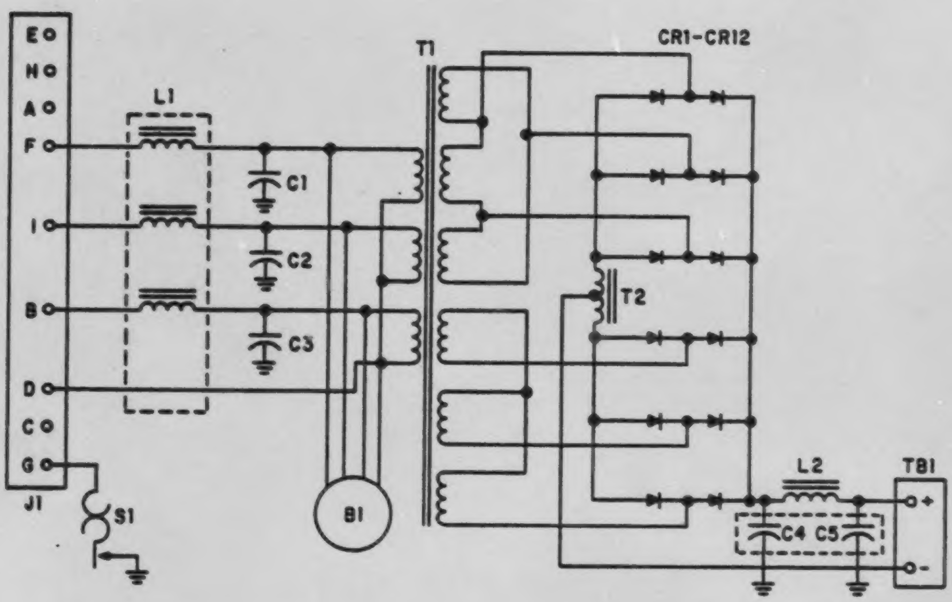


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Figure 6-13.—Schematic diagram of a typical transformer-rectifier.

beyond about 8 or 10. A feature which is sometimes objectionable is that there is no isolation between primary and secondary positions of the circuit. For this reason it is not employed to step down a very high voltage as there is danger that the secondary may be subjected to the high primary voltage.

Referring to figure 6-14, a saving in wire results from the fact that both the source current and the secondary current flow through the load. The secondary winding is connected in a direction so as to add to the current flowing through the primary. Current is generally the governing factor in determining the size of a conductor. The maximum current necessary through any conductor in this autotransformer is 5 amperes to supply a 10-ampere load. Therefore, the transformer can be smaller than a regular transformer where the secondary must supply the full 10-ampere load. The autotransformer has a disadvantage, however, in that the secondary is not isolated from the source voltage as is the secondary of a regular transformer. The turns ratio and other details of the circuit are determined in the same manner as for conventional transformers.

The circuit in figure 6-14 shows an autotransformer with a turns ratio of 2-to-1 stepdown, the tap at point B dividing the winding into two equal parts. With a load of 5 ohms connected as shown, the load current is computed by the formula I=E/R or 50/5=10 amperes. The power in the load therefore equals EI (50 x 10) or 500 watts. As in a regular transformer, this power comes from the primary by means of the magnetic field and, disregarding losses, the primary must take 500 watts from the line. The primary current would therefore be P/E (500/100) or 5 amperes. Only the difference between these two currents, which is 5 amperes, flows in the common portion C to B, as indicated by the arrow. Thus, when the turns ratio is 2:1 (either step-up or stepdown), the current in both sections of the winding is the same, and the cost and weight of an entire winding are saved.

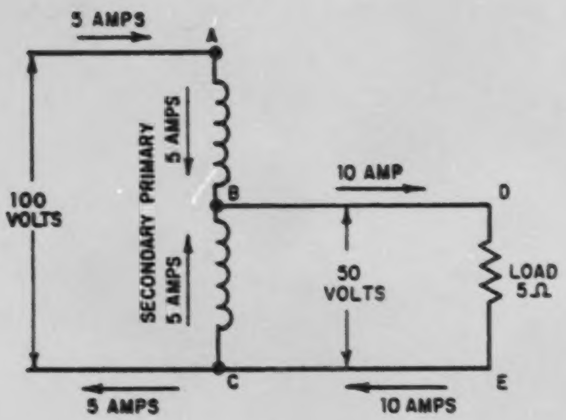

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Figure 6-14.—2:1 ratio Autotransformer.

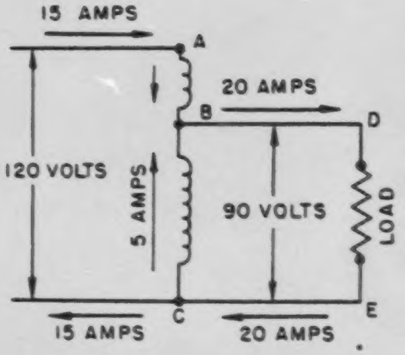

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Figure 6-15.—1.33:1 ratio Autotransformer.

The autotransformer in figure 6-15 has a turns ratio of 1.33:1 connected to a load which draws 20 amperes. This represents a secondary power of EI=(90 x 20) or 1,800 watts. The primary current, neglecting losses, equals P/E (1,800/120) or 15 amperes. As in the previous problem, the current in that portion of the winding from B to C which is common to both circuits is the difference between the primary and secondary line currents, or 5 amperes. The saving here is obvious. A conventional transformer of the same characteristics would require a 120-volt 15-ampere primary and a separate 90-volt 20-ampere secondary. Here all that is required is a 30-volt 15-ampere winding in series with a 90-volt 5-ampere winding, provided, of course, that the application at hand permits the use of an autotransformer. Thus, a 0.45 kva autotransformer will supply this 1.8 kva load.

There are many interesting uses of autotransformers. An autotransformer with a continuous variable tap is marketed under the name VARIAC, and is used for many purposes where a continuous control from zero to full (or even above) line voltage is required. The core in this case is made in the form of a ring (toroid), and the winding is usually in the form of a single layer covering almost the entire surface. A control shaft carries an arm and a brush which makes contact with each turn of the winding as the shaft is rotated. Thus, the setting of the shaft determines the turns ratio. One end of the winding goes to both line and load, and the other end goes to the line. The brush is connected to the other side of the load. If it is desired to obtain voltages in excess of line voltage, such as to compensate for abnormally low line voltage, the primary is connected to a tap approximately 10 percent down from the end of the winding. This provides secondary control from zero to full line voltage, even though the actual line voltage is as much as 10 percent below normal.

INSTRUMENT TRANSFORMERS

It is usually not practicable to connect meters directly to high-voltage and high-current a-c circuits. Therefore, meters are coupled to these circuits by means of instrument transformers. These transformers are divided into two general types—the current and the potential. These devices permit the use of standard low-voltage meters for all high-voltage or high-current a-c circuits, and at the same time protect the operating personnel from the high-voltage circuits. Instrument transformers are covered in detail in Basic Electricity, NavPers 10086-B.

ELECTRONIC POWER SUPPLIES

In our modern day high performance aircraft, avionics systems have been developed so that the pilot may communicate, navigate or fire missiles. Other systems have been designed to ease the pilot's workload, such as radar and autopilot systems. Each of these avionics systems requires precision voltage inputs for proper operation.

For instance, an inertial navigation system may require the voltages shown in table 6-1. The voltages required by an autopilot in the same aircraft may be seen in table 6-2.

It then becomes obvious that one simple electrical power source will not provide all of the needed power for the 20 or 30 different avionics systems in each type aircraft.

Each avionics system will normally have its own power supply. Figure 6-16 shows the power supply used with the PB-20N autopilot system. The electrical power input requirement is 120/208 volts, 3-phase, 4-wire, 400-hertz and produces the voltages listed in table 6-2. The majority of the output voltages are produced by three autotransformers shown in figure 6-17 as T4, T5, and T6. The autotransformers are manufactured with taps from each transformer winding at the proper position to produce the required voltage. Under fairly constant load conditions, no further voltage regulation is necessary.

D-c voltages may be produced by full wave rectifiers as shown in figure 6-18, which is also employed in the PB-20N power supply. Each pair of rectifiers (either CR7 and CR10, or CR8 and CR9) will conduct during alternate half cycles of the a-c input from the secondary of stepdown transformer T7. The unfiltered d-c is then used to operate lights and relays for internal operation of the PB-20N, and is also fed to a filter network. The filtered d.c. is used to supply transistor bias to the electronic amplifiers in the PB-20N autopilot.

The circuit shown in figure 6-19 may be used to develop precision d-c voltages. Diode CR1 is a zener diode which will develop a constant d-c voltage at the input of amplifier A1, regardless of fluctuations in the input voltage. If the d-c input voltage at the top of R1 increases, CR1 will conduct harder and the excess voltage will be dropped across R1. If the voltage decreases, CR1 will conduct less and less voltage will be

Table 6-1.–Electrical requirements for an inertial navigation system

D-c	A-c
+45 V transistor bias	26 V, 400 hertz
-45 V transistor bias	140 V, 400 hertz, 3 phase
+28 V unfiltered and unregulated	90 V, 375 hertz, 3 phase
+28 V transistor bias	12.6 V, 400 hertz
+28 V unregulated, relay excitation	6.3 V, 400 hertz
+20 V transistor bias	
+10 V reference	
-10 V reference	

Table 6-2.–Electrical requirements for a typical transistorized autopilot system

Phase A	Phase B	Phase C	DC
120 VAC	120 VAC	120 VAC	28 V filtered
45 VAC	26 VAC	15 VAC	28 V unfiltered
26 VAC	15 VAC	10 VAC	
19 VAC			
15 VAC			
7 VAC			

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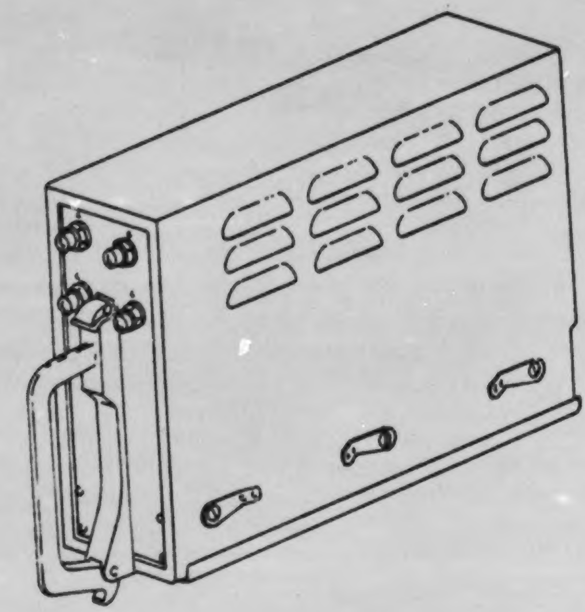

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Figure 6-16.—Typical electronic power supply.

dropped across R1, maintaining the voltage at the anode of CR1 at a constant, precision potential.

Considering no current flow through R2, then the same potential will be present at the input of amplifier A1 as is on the anode of CR1. The gain of amplifier A1 is controlled by feedback voltage through R3 and R4. If the combined resistance values of R3 and R4 are the same as the resistance of R2, then the output voltage will be at the same potential as that on the anode of CR1. Variable resistor R4 may be used to fine tune the output voltage to the desired level. Isolation amplifier A1 prevents changes in the load current from being felt at the zener diode.

There are many methods of providing precision voltages, both d-c and a-c, by the use of either transistors or electron tubes, and frequencies of a-c voltages may be changed. Several of these methods are discussed in Basic Electronics, Vol I, NavPers 10087-C, Chapters 5 through 8.

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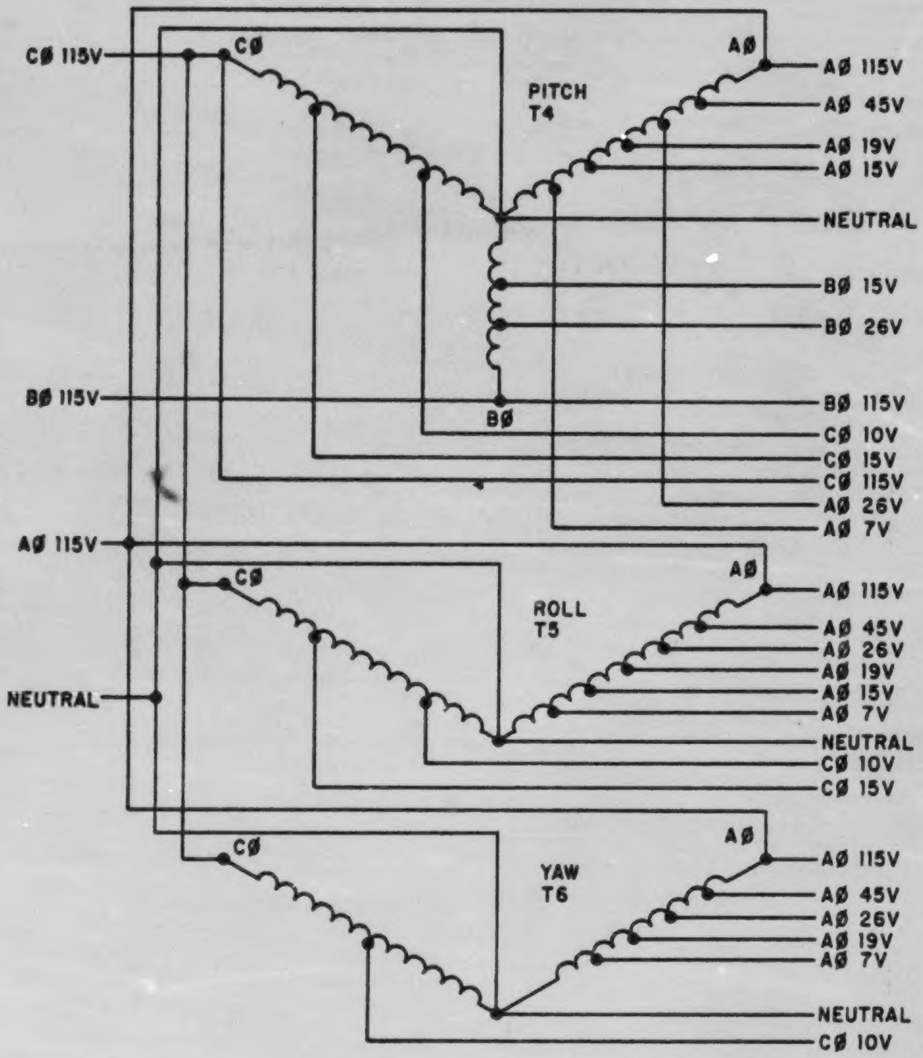
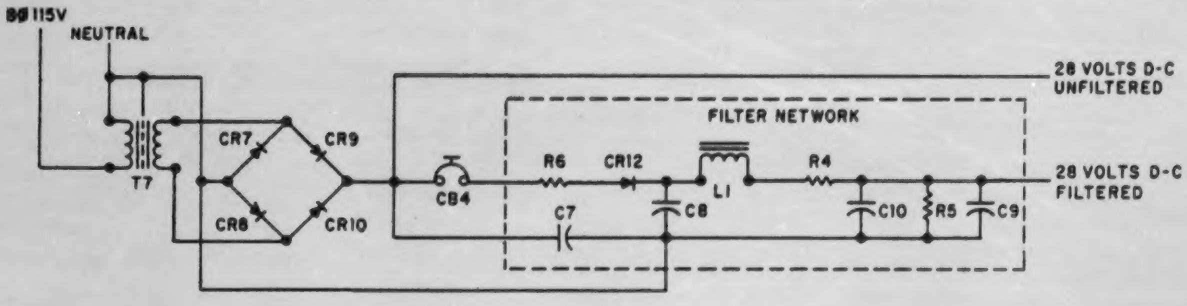

CØ 115V
CØ
AØ
PITCH
T4
AØ 115V
AØ 45V
AØ 19V
AØ 15V
NEUTRAL
BØ 15V
BØ 26V
BØ 115V
BØ
BØ 115V
CØ 10V
CØ 15V
CØ 115V
AØ 26V
AØ 7V
AØ 115V
CØ
AØ
ROLL
T5
AØ 115V
AØ 45V
AØ 26V
AØ 19V
AØ 15V
AØ 7V
NEUTRAL
NEUTRAL
CØ 10V
CØ 15V
CØ
AØ
YAW
T6
AØ 115V
AØ 45V
AØ 26V
AØ 19V
AØ 7V
NEUTRAL
CØ 10V

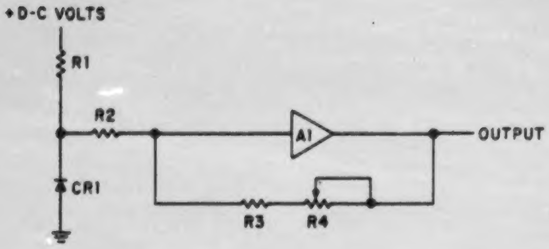
AE.762

Figure 6-17.–Developing a-c voltages for the PB-20N autopilot.


BØ 115V
NEUTRAL
T7
CR7
CR9
CR8
CR10
CB4
FILTER NETWORK
R6
CR12
L1
R4
C7
C8
C10
R5
C9
28 VOLTS D-C UNFILTERED
28 VOLTS D-C FILTERED

AE.763

Figure 6-18.—Full wave rectifier and filter network.


+D-C VOLTS
R1
R2
A1
OUTPUT
CR1
R3
R4

AE.764

Figure 6-19.—Precision d-c voltage developer.

Airman NAVPERS 10307-C 517

2-5

CHAPTER 3

AIRCRAFT FUNDAMENTALS

The mystery of flying has always puzzled man. Stories of his efforts to fly can be found in the myths and legends that precede recorded history. The earliest available aeronautical history is found in the Greek legend which tells the story of two men who made wings of wax and attempted to fly. It was not, however, until the successful flight by the Wright Brothers at Kitty Hawk, North Carolina, that the dream of how to fly became a reality. In the half century since Kitty Hawk, aircraft designers have spent years of research in developing the aircraft from the crude vehicle of the Carolina sand dunes to the modern aircraft of today.

THEORY OF FLIGHT

AERODYNAMICS

Theory of flight deals with aerodynamics. The term is derived from the combination of two Greek words—"aer" meaning air, and "dyne" meaning force or power. Thus, when aero is joined with dynamics, we have aerodynamics, meaning the study of objects in motion through the air and the forces that produce or change such motion.

Aerodynamics is the science of the action of air on an object. It is further defined as that branch of dynamics dealing with the motion of air and other gases, with the forces acting upon an object in motion through the air, or with an object which is stationary in a current of air. The latter is a great help to aeronautical engineers because it enables them to experiment with a model aircraft in a wind tunnel before the aircraft is built. In effect, aerodynamics is concerned with three distinct parts—the object, the movement, and the air. These parts may be defined as the aircraft, the relative wind, and the atmosphere.

THE ATMOSPHERE

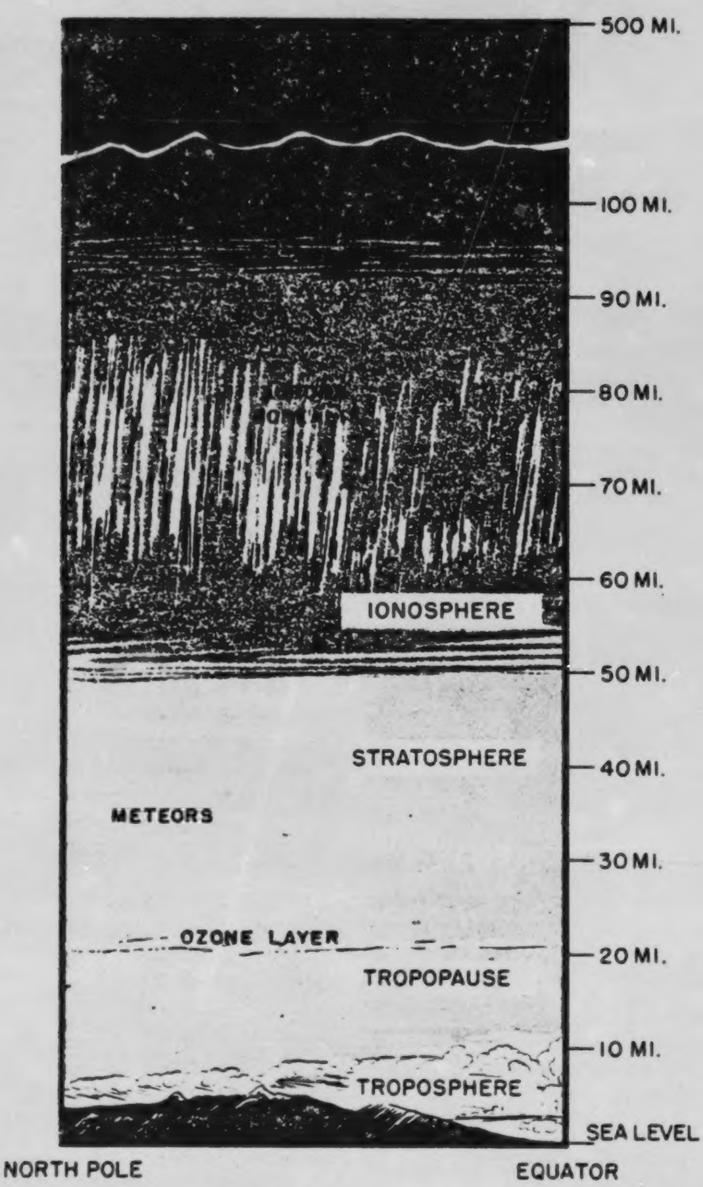
Before discussing the fundamentals of the theory of flight, there are several basic ideas that must be considered. An aircraft operates in the air; therefore, the properties of air that affect aircraft control and performance must be understood.

To begin with, what is air? It is a mixture of gases consisting of about 78 percent nitrogen, 21 percent oxygen, and the remaining 1 percent consists of numerous other gases including argon, carbon dioxide, hydrogen, and helium. Since air is a combination of gases, it follows the laws of gases. Air is considered a fluid because it answers the definition of a fluid—namely, a substance which may be made to flow or change its shape by the application of moderate pressure. Air has weight since something lighter than air, such as a balloon filled with helium, will rise in the air.

The atmosphere is the whole mass of air surrounding the earth. While it extends upward for an indefinite height, most flying takes place in that portion which rests on the earth's surface and extends upward through the troposphere and the lower regions of the stratosphere. (See fig. 3-1.) This area contains moving currents of air called wind, various types of clouds, snow, rain, hail, and the four seasonal changes.

PRESSURE

The deeper a diver goes beneath the surface of the ocean, the greater the pressure becomes on his body due to the weight of the water overhead. Since air also has weight, the greater the depth from the outer surface of the atmosphere, the greater the pressure. If a 1-inch square column of air extending from sea level to the "top" of the atmosphere could be weighed, it would be found to weigh about 14.7 pounds. Thus, atmospheric pressure at sea level is


500 MI.
100 MI.
90 MI.
80 MI.
70 MI.
60 MI.
IONOSPHERE
50 MI.
STRATOSPHERE
40 MI.
METEORS
30 MI.
OZONE LAYER
20 MI.
TROPOPAUSE
10 MI.
TROPOSPHERE
SEA LEVEL
NORTH POLE
EQUATOR

AN.10

Figure 3-1.—The earth's atmosphere.

14.7 pounds per square inch (psi). However, pounds per square inch is rather a crude unit for the measurement of a light substance such as air. Therefore, atmospheric pressure is usually measured in terms of inches of mercury.

The apparatus for measuring atmospheric pressure is shown in figure 3-2. A glass tube 36 inches long, open at one end and closed at the other, is filled with mercury. The open end is sealed temporarily and then submerged into a small container partly filled with mercury, after which the end is unsealed. This allows the mercury in the tube to descend, leaving a vacuum at the top of the tube. Some of the mercury flows into the container while a portion of it remains in the tube. The weight of the atmosphere pressing on the mercury in the open container exactly balances the weight of the mercury in the tube, which has no atmospheric pressure pushing down on it due to the vacuum in the top of the tube. As the pressure of the surrounding air decreases or increases, the mercury column lowers or rises correspondingly. At sea level the height of the mercury in the tube measures approximately 29.92 inches, although it varies slightly with the weather.

An important consideration is that atmospheric pressure varies with altitude. The higher an object rises above sea level, the lower the pressure. At 5,000 feet the pressure is approximately 24.89 inches of mercury; at 10,000 feet it is about 20.58 inches; and at 20,000 feet it is only 13.75 inches.

The fact that air pressure is greater at sea level and gradually diminishes as altitude increases plays an important role in flying. Since this decrease in air pressure is proportional to the height above sea level, the apparatus shown in figure 3-2 can serve as a crude indicator of altitude. The higher the altitude, the less the pressure to support the column of mercury. A scale can then be devised to show the height above the earth.

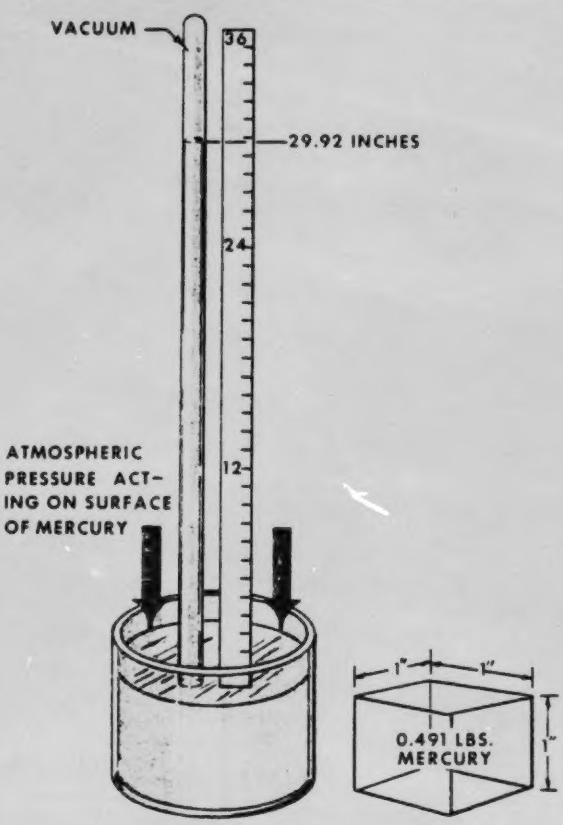
Various atmospheric conditions have a definite relation to flying. The effect of temperature, altitude, and density of air on aircraft performance is discussed in the following paragraphs.

DENSITY

Density is a term that means weight per unit volume. Since air is a mixture of gases it can be compressed. If the air in one container is under one-half as much pressure as the air in another identical container, the air under the greater pressure weighs twice as much as that in the container under lower pressure. The air under greater pressure is twice as dense as that in the other container. For equal weights of air, that under the greater pressure occupies only half the volume of that under half the pressure.

The density of gases is governed by the following rules:

1. Density of gases varies in direct proportion with the pressure. Thus, air at high altitudes is less dense than air at low altitudes.



AN.11

Figure 3-2.—Measurement of atmospheric pressure.

2. Density of gases at the same altitude varies inversely with temperature. Thus, a mass of hot air is less dense than a mass of cool air.

Changes in density affect the aerodynamic performance of aircraft. With the same horsepower, an aircraft can fly faster at a high altitude where the density is low than at a low altitude where the density is great. This is because air offers less resistance to the aircraft when it contains a smaller number of air particles per unit volume.

HUMIDITY

Humidity is the amount of water vapor in the air. The maximum amount of water vapor that air can hold varies with the temperature. The higher the temperature of the air, the more water vapor it can absorb. By itself, water vapor weighs approximately five-eights as much as an equal amount of perfectly dry air. Therefore, when air contains water vapor it is not as heavy as air containing no moisture.

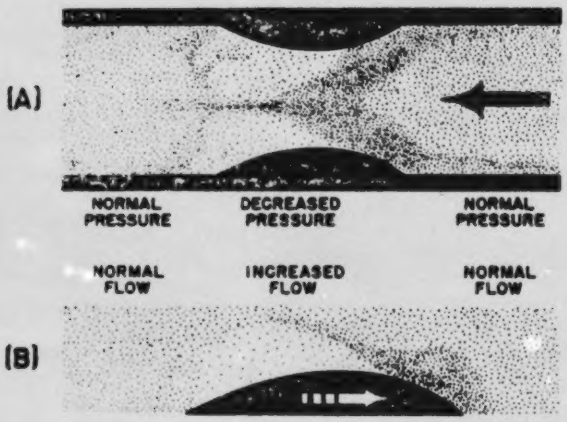
Assuming that the temperature and pressure remain the same, the density of the air varies inversely with the humidity. On damp days the density is less than on dry days. For this reason, an aircraft requires a longer runway for takeoff on damp days that it does on dry days.

BERNOULLI'S PRINCIPLE

Air, being a fluid, is affected by Bernoulli's principle. The principle states that when a fluid flowing through a tube reaches a constriction, or narrowing of the tube, the speed of the fluid flowing through that constriction is increased and its pressure is decreased. Likewise, the cambered (curved) surface of an airfoil (wing) affects the airflow exactly as a constriction in a tube affects fluid flow. This resemblance is illustrated in figure 3-3.

Diagram (A) of figure 3-3 illustrates the effect of air passing through a constriction in a tube. In (B), the air is flowing past a cambered surface, such as an airfoil, and the effect is similar to that of air passing through a restriction.

As the air flows over the upper surface of an airfoil, its speed or velocity increases and its pressure drops. An area of low pressure is thus formed. There is an area of greater pressure on the lower surface of the airfoil, and this greater pressure tends to move the wing upward. This difference in pressure between the upper and lower surfaces of the wing is called lift. Three-fourths of the total lift of an airfoil is the result of the decrease in pressure over the upper surface. The impact of air on the under surface of an airfoil produces the other one-fourth of the total lift.



AN.12

Figure 3-3.—Bernoulli's principle.

An aircraft in flight is acted upon by four forces: Gravity, or weight, is the force pulling the aircraft toward the earth; lift is the force pushing the aircraft upward; thrust is the force that speeds the aircraft forward; and drag is the force exerting a braking action. Three of these forces—lift, thrust, and drag—depend upon the action of the air.

MOTION

Motion is the act or process of changing place or position. An object may be in motion with respect to one object and motionless with respect to another. For example, a person sitting quietly in an aircraft flying at 200 knots is at rest or motionless with respect to the aircraft; however, the person is in motion with respect to the air or the earth, the same as is the aircraft.

Air has no force or power, except pressure, unless it is in motion. When it is moving, however, its force becomes apparent. A moving object in motionless air has a force exerted on it as a result of its own motion. It makes no difference in the effect then, whether an object is moving with respect to the air or the air is moving with respect to the object.

The flow of air around an object caused by the movement of either the air or the object, or both, is called the relative wind. A person up in a free balloon feels no breeze even if the wind is blowing at 50 knots. The balloon is supported by the air and is moving relative to the ground at 50 knots, but it is stationary with respect to the air. When model aircraft are tested in a wind tunnel, it is not practical to force them through the air. They are held stationary and the air is forced past them at high velocity.

Velocity and Acceleration

The terms "speed" and "velocity" are often used interchangeably, but they do not mean the same. Speed is the rate of motion, and velocity is the rate of motion in a particular direction.

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An aircraft starts from New York City and flies 10 hours at an average speed of 300 miles per hour. At the end of this time the aircraft may be over the Atlantic Ocean, the Pacific Ocean, the Gulf of Mexico, or, if its flight was in a circular path, it may even be back over New York. If this same aircraft flew at a velocity of 300 miles per hour in a southwestward direction it would arrive in Los Angeles in about 10 hours. Only the rate of motion is indicated in the first example and denotes the speed of the aircraft. In the last example the particular direction is included with the rate of motion, thus, denoting the velocity of the aircraft.

Acceleration is defined as the rate of change of velocity. An aircraft increasing in velocity is an example of positive acceleration, while another aircraft reducing its velocity is an example of negative acceleration. (Positive acceleration is often referred to as acceleration and negative acceleration as deceleration.)

Newton's Laws of Motion

The fundamental laws governing the action of air about a wing are Newton's laws of motion.

Newton's first law is normally referred to as the law of inertia. It simply means that a body at rest will not move unless force is applied to it. If it is moving at uniform speed in a straight line, force must be applied to increase or decrease that speed.

Since air has mass, it is a "body" in the meaning of the law. When an aircraft is on the ground with its engines dead, inertia keeps the aircraft at rest. An aircraft is moved from its state of rest by the thrust force created by the propeller, by the expanding exhaust gases, or both. When it is flying at uniform speed in a straight line, inertia tends to keep the aircraft moving. Some external force is required to change the aircraft from its path of flight.

Newton's second law, that of force, also applies to objects. This law states that if a body moving with uniform speed is acted upon by an external force, the change of motion will be proportional to the amount of the force, and motion will take place in the direction in which the force acts. This law may be stated mathematically as follows: Force equals mass time acceleration ($F = ma$).

If an aircraft is flying against a headwind, it is slowed down. If the wind is coming from either side of the aircraft's heading, the aircraft is pushed off course unless the pilot takes corrective action against the wind direction.

Newton's third law is the law of action and reaction which states: For every action (force) there is an equal and opposite reaction (force). This law is well illustrated by the action of a swimmer's hands. He pushes the water aft and therby propels himself forward, since the water resists the action of his hands. When the force of lift on an aircraft's wing equals the force of gravity, the aircraft maintains level flight.

The three laws of motion which have been discussed are closely related and apply to the theory of flight. In many cases, all three laws may be operating on an aircraft at the same time.

THE AIRFOIL

An airfoil is a surface designed to obtain a desirable reaction from the air through which it moves. Thus, any part of the aircraft which converts air resistance into a force useful for flight is an airfoil. The propeller blades, wings, control surfaces, and stabilizers are some of the aircraft parts classified as airfoils. The cross section of an aircraft wing, shown in figure 3-4, is an excellent example of an airfoil. Although the wing is used as an example in the following paragraphs, the discussion applies to all airfoils.

The front edge of the wing is called the leading edge and the rear edge is called the trailing edge. An imaginary straight line between the leading edge and the trailing edge is known as the chord.

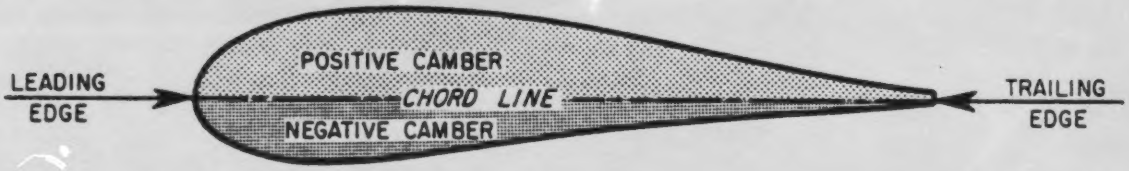

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Figure 3-4.—Cross section of an airfoil.

The chord varies in length from the fuselage to the wingtip.

The surface of the airfoil seldom follows the chord. This curve, or departure from a straight line, is known as camber. The top curvature of the airfoil is called the upper camber. If the shape of the surface is convex, such as the upper surface of a wing, it is referred to as positive camber. If the shape of the surface is concave, it is said to have negative camber. A flat surface has zero camber. The under surface of a wing usually has positive, although it may be negative or zero camber. In level flight, the leading edge of the wing is higher than the trailing edge. The airstream strikes the airfoil and separates, part going above and part going below. The part going above the airfoil—over the upper surface—causes a drop in atmospheric pressure thereby creating a lift. The part going below the airfoil—along the undersurface—creates undersurface lift.

You have probably held your flattened hand out of the window of a moving automobile. As you inclined your hand to the wind, the force of air against it pushed it up. This is a good demonstration of how an aircraft gets about 25 percent of its lift. The airfoil (in this case your hand) was deflecting the wind downward which, according to Newton's third law of motion (for every action there is an equal and opposite reaction) created an equal and opposite effect, forcing your hand upward. This upward force is called lift.

However, if all the lift required were obtained merely from the deflection of air by the lower surface of the airfoil, an aircraft would need only a flat wing. This is not the case at all. For one reason, disturbed air currents at the trailing edge of the airfoil would be excessive and make the aircraft lose velocity and lift. The balance of the lift needed to support the aircraft must come from the flow of air above the wing.

Many thousands of airfoils have been tested in wind tunnels and actual flight, but no one airfoil has been found that satisfies every requirement. The weight, speed, and purpose of each aircraft dictate the shape of the airfoil. It was learned years ago that the most efficient airfoil for producing the greatest lift was one that had a concave, or scooped out lower surface. However, it was also proven that this type of airfoil sacrificed too much speed while producing lift. It was also found that the larger the wingspan as compared to the chord, the greater the lift obtained. This comparison is called "aspect ratio." In aerodynamic terminology the higher the aspect ratio, the greater the lift. In spite of the benefits from an increase in aspect ratio it was found that definite limitations were imposed because of structural and drag considerations.

On the other hand, an airfoil that is perfectly streamlined and offers little wind resistance sometimes does not have enough lifting power to take the aircraft off the ground. Thus, modern aircraft have airfoils which strike a medium between extremes, with the shape varying according to the needs of the aircraft for which it is designed.

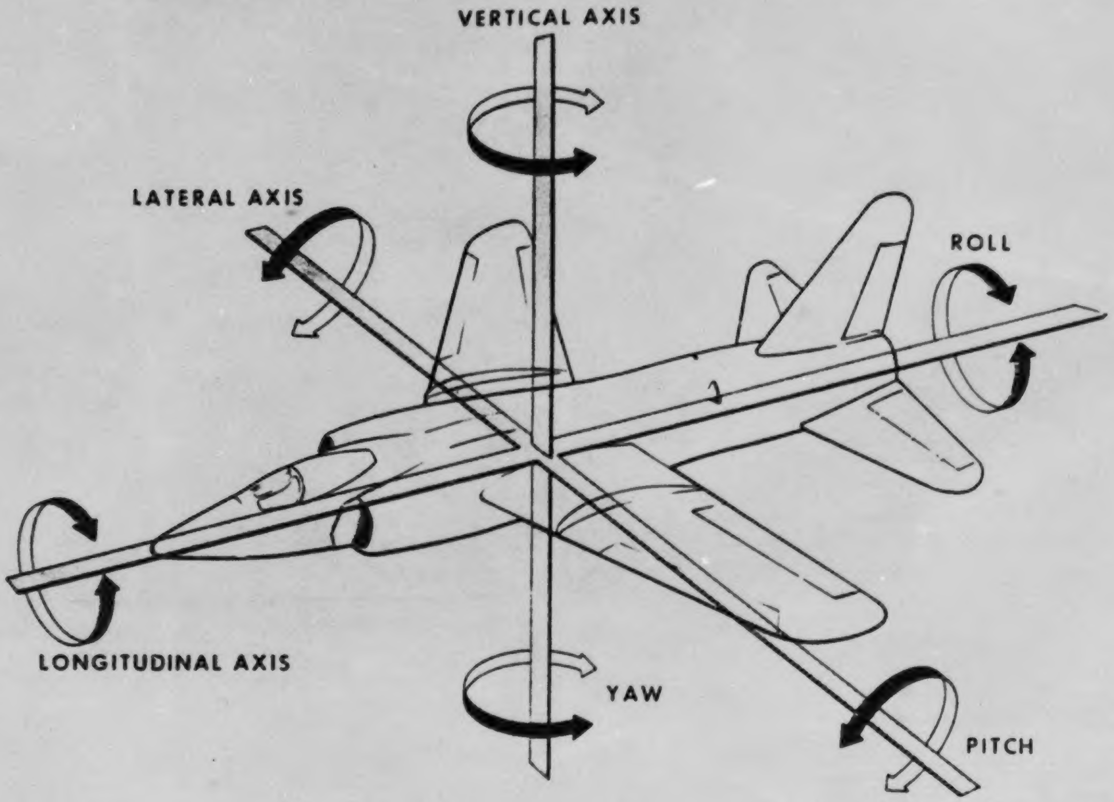
AXES OF AN AIRCRAFT

Whenever an aircraft changes its attitude in flight, it must turn about one or more of three axes. Figure 3-5 shows the three axes, which are imaginary lines passing through the center of the aircraft. The axes of an aircraft can be considered as imaginary axles around which the aircraft turns like a wheel. At the center, where all three axes intersect, each is perpendicular to the other two. The axis which extends lengthwise through the fuselage from the nose to the tail is called the longitudinal axis. The axis which extends crosswise, from wingtip-to-wingtip, is the lateral axis. The axis which passes through the center, from top to bottom, is called the vertical axis.

Motion about the longitudinal axis resembles the roll of a ship from side to side. In fact, the names used in describing the motion about an aircraft's three axes were originally nautical terms. They have been adapted to aeronautical terminology because of the similarity of motion between an aircraft and a ship.

Thus, the motion about the longitudinal axis is called roll. Likewise, motion along the lateral (crosswing) axis is called pitch. This is similar to the pitching motion of an ocean vessel as it plows into heavy seas. Finally, an aircraft moves about its vertical axis in a motion which is termed yaw. This is a horizontal movement of the nose of the aircraft.

Roll, pitch, and yaw—the motions an aircraft makes about its longitudinal, lateral, and vertical axes—are controlled by three control surfaces. Roll is produced by the ailerons, which are located at the trailing edges of the wings. Pitch is affected by the elevators, the rear portion of the horizontal tail assembly. Yaw is controlled



AN.14

Figure 3-5.—The axes of an aircraft.

by the rudder, the rear portion of the vertical tail assembly.

ANGLE OF INCIDENCE

The acute angle which the wing chord make with the longitudinal axis of the aircraft is called the angle of incidence, or the angle of wing setting. The angle of incidence in most cases is a fixed, built-in angle. When the leading edge of the wing is higher than the trailing edge, the angle of incidence is said to be positive. The angle of incidence is negative when the leading edge is lower than the trailing edge of the wing.

ANGLE OF ATTACK

The angle of attack of an airfoil is the angle between the chord and the relative wind, as shown in figure 3-6. The angle of attack changes as the aircraft moves up or down. Since the angle of attack has a great deal to do with determining lift, it is given primary consideration when designing airfoils. In a properly designed airfoil, the lift increases as the angle of attack is increased.

When the angle of attack increases to the angle of maximum lift, the burble point is reached. This is known as the critical angle. When the critical angle is reached, the air ceases to flow smoothly over the surface and begins to burble, or eddy. This means that air breaks away from the upper camber line of the wing. What was formerly the area of decreased pressure is now filled by this burbling air. When this occurs, the amount of lift drops and drag becomes excessive. The force of gravity exerts itself, and the nose of the aircraft drops. Thus we see that the burble point is the stalling angle. In order to recover flying speed, the nose of the aircraft should be dropped until flying speed has been regained and wing lift restored.

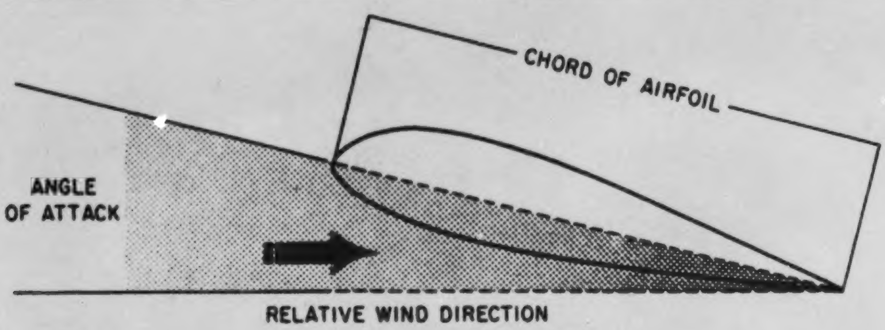


Figure 3-6.–Angle of attack.

CENTER OF PRESSURE

As we have seen, the distribution of the individual pressure and suction forces over the airfoil varies with the angle of attack. The application of the resultant force, that is, the center of pressure, varies correspondingly. As this angle increases, the center of pressure moves forward; and as the angle decreases, the center of pressure moves back. The unstable travel of the center of pressure is characteristic of practically all airfoils.

CENTER OF GRAVITY

Gravity is the pulling force that tends to draw any two bodies together. The center of gravity may be considered as a point at which all the weight of the aircraft is concentrated. If the aircraft were supported at its exact center of gravity, it would balance in any position. Center of gravity is of major importance in an aircraft, for its position has a great bearing upon stability.

The center of gravity is determined by the general design of the aircraft. The designer estimates how far the center of pressure will travel. He then fixes the center of gravity in front of the center of pressure for the corresponding flight speed in order to provide adequate restoring moment for free flight equilibrium.

THRUST AND DRAG

An aircraft in flight is the center of a continuous battle of forces. Actually, this conflict is not as violent as it sounds, but it is the key to all maneuvers performed in the air. There is nothing mysterious about these forces; they are definite and known. The directions in which they act can be calculated; and the aircraft itself is designed to take advantage of each of them. In all types of flying, flight calculations are based on the magnitude and direction of four forces: lift, weight, drag, and thrust.

Weight is the force of gravity acting downward upon everything that goes into the aircraft, such as the aircraft itself, the crew, the fuel, and the cargo.

Lift, as we have seen, acts vertically and by so doing counteracts the effects of weight.

Drag is a backward deterrent force and is caused by the disruption of the airflow by the wings, fuselage, and protruding objects.

Thrust produced by the powerplant is the forward force that overcomes the force of drag.

Now, to see how these four forces are constantly fighting for superiority, and how to keep them in proper balance, examine them a bit more closely. You will see that they are only in perfect balance when the aircraft is in straight and level unaccelerated flight.

The force of lift and drag are the direct result of the relationship between the relative wind and the aircraft. The force of lift always acts perpendicular to the relative wind, and the force of drag always acts parallel to the relative wind and in the same direction. These forces are actually the components that produced a resultant lift force on the wing as shown in figure 3-7.

In actual flight, there are two forces acting on an aircraft—weight and thrust. Weight has a definite relationship with lift, and thrust with drag. This relationship is quite simple, but very important in understanding the aerodynamics of flying. As stated previously, lift is the upward force on the wing acting perpendicular to the relative wind. Lift is required to counteract the aircraft's weight, caused by the force of gravity acting on the mass of the aircraft. This weight force acts downward

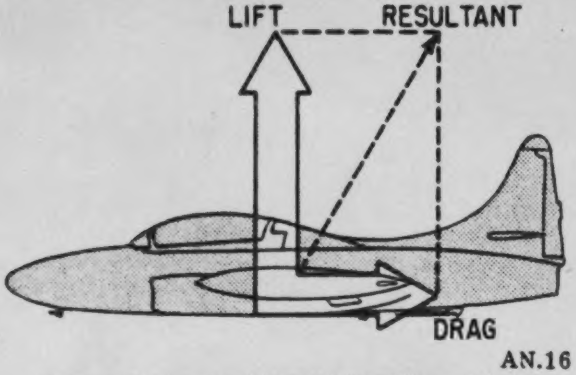


Figure 3-7.—Resultant of the lift and drag.

through a point called the center of gravity which is the point at which all the weight of the aircraft is considered to be concentrated. When the lift force is in equilibrium with the weight force, the aircraft neither gains nor loses altitude. If lift becomes less than weight, the aircraft loses altitude. When the lift is greater than weight, the aircraft gains altitude.

Drag must be overcome in order for the aircraft to move, and movement is essential to obtain lift. To overcome the drag and move the aircraft forward, another force is essential. This force is thrust. Thrust is derived from jet propulsion or from a propeller and engine combination. Jet propulsion theory is based on Newton's third law of motion which states that for every action there is an equal and opposite reaction. For example, in firing a gun the action is the bullet going forward while the reaction is the gun recoiling backwards. The jet engine causes a mass of air to be moved backward at high velocity causing a reaction forward that moves the aircraft.

In a propeller and engine combination, the propeller is actually two or more revolving airfoils mounted on a horizontal shaft. The motion of the blades through the air produces lift similar to the lift on the wing, but acting in a horizontal direction, pulling the aircraft forward.

Before the aircraft begins to move, thrust must be exerted. It continues to move and gain speed until thrust and drag are equal. In order to maintain a steady speed, thrust and drag must remain equal, just as lift and weight must be equal for steady, horizontal flights. We have seen that increasing the lift means that the aircraft moves upward, whereas decreasing the lift so that it is less than the weight causes the aircraft to lose altitude. A similar rule applies to the two forces of thrust and drag. If the rpm of the engine is reduced, the thrust is lessened, and the aircraft slows down. As long as the thrust is less than the drag, the aircraft travels more and more slowly until its speed is insufficient to support it in the air.

Likewise, if the rpm of the engine is increased, thrust becomes greater than drag, and the speed of the aircraft increases. As long as the thrust continues to be greater than the drag, the aircraft continues to accelerate. When drag equals thrust, the aircraft flies at a steady speed.

The relative motion of the air over an object that produces lift also produces drag. Drag is the resistance of the air to objects moving through it. If an aircraft is flying on a level course, the lift force acts vertically to support it while the drag force acts horizontally to hold it back. The total amount of drag on an aircraft is made up of many drag forces, but for our purposes, we consider three—parasite drag, profile drag, and induced drag.

Parasite drag is made up of a combination of many different drag forces. Any exposed object on an aircraft offers some resistance to the air, and the more objects in the airstream, the more parasite drag. While parasite drag can be reduced by making the number of different parts as few as practical and giving all exposed parts a streamlined shape, skin friction is the type of parasite drag most difficult to reduce. No surface is perfectly smooth. Even machined surfaces when inspected under magnification have a ragged uneven appearance. These ragged surfaces deflect the air near the surface causing resistance to smooth airflow. Skin friction can be cut down by employing glossy flat finishes and eliminating protruding rivet heads, roughness, and other irregularities.

Profile drag may be considered the parasite drag of the airfoil. The various components of parasite drag are all of the same nature as profile drag.

The action of the airfoil that gives us lift (at the same time) causes induced drag. Remember that the pressure above the wing is less than atmospheric, and the pressure below the wing is equal to or greater than atmospheric pressure. Since fluids always move from high pressure toward low pressure, there is a movement of air from the bottom of the wing outward from the fuselage and upward around the wingtip. This flow of air results in "spillage" over the wingtip, thereby setting up a whirlpool of air called a vortex. The air on the upper surface has a tendency to move in toward the fuselage and off the trailing edge. This air current forms a similar vortex at the inner portion of the trailing edge of the wing. These vortexes increases drag, because of the turbulence produced, and constitute induced drag.

Just as lift increases with an increase in angle of attack, induced drag also increases as the angle of attack becomes greater. This occurs because as the angle of attack is increased, there is a greater pressure difference between the top and bottom of the wing. This causes more violent vortexes to be set up, resulting in more turbulence and more induced drag.

HIGH-PERFORMANCE AIRCRAFT

With the advent of supersonic aircraft and guided missiles, many new and challenging problems have been encountered. A discussion of high-speed flying requires a different yardstick of measurement than that formerly used in measuring indicated or true airspeed.

It is no longer sufficient to give airspeed in miles per hour. The speed of aircraft and guided missiles is now spoken in terms of the speed of sound. A new term "Mach number" has come into wide use. The ratio of the aircraft's speed to the speed of sound at the flying altitude is called the Mach number. Mach 1 is equal to the speed of sound. The speed of sound varies with the altitude and temperature; however, the general reference to the speed of sound is about 760 miles per hour at sea level. Subsonic Mach numbers are less than 1 and supersonic Mach numbers are greater than one. The areas and speeds at which aircraft operate are further defined approximately as follows:

Subsonic—Mach numbers below 0.75.
Transonic—Mach numbers from 0.75 to 1.20
Supersonic—Mach numbers from 1.21 to 5.00.
Hypersonic—Mach numbers above 5.00.

Another term which is often used when discussing high performance aircraft is "compressibility." Conpressibility or compressibility effect may cause vibration or flutter in certain members of the aircraft, if conventionally designed aircraft are flown at high speeds. This, in part, accounts for some of the unusual physical designs and unusual control systems. Examples are "coke bottle design," variable incidence wings, and boundary layer control devices.

Flight in the transonic range presents many problems. Control and stability are probably the greatest of these. On an aircraft below this speed the air flows over the wing and is deflected downward over the elevators. This angle is called the downwash angle and it decreases as the lift decreases. The supersonic flow over the wings and tail surface is very uniform. There is no abrupt change in either lift or drag. The problem of control becomes very difficult in the transonic speed range. At this speed the lift is greatly reduced and the aircraft tends to dive. Once an uncontrollable dive is started, control can be regained by either accelerating into the supersonic range, or by decelerating into the subsonic range. When the flow of air over the wings and tail surfaces becomes supersonic; some control and stability returns. If the aircraft cannot reach the supersonic range it continues to dive to a lower altitude where the density is greater and the temperature higher. These effects combine to return the aircraft to subsonic speed.

STABILITY AND CONTROL

Without some means of stabilization and control, an aircraft could move freely on any or all of its axes at the whim of any air current or imbalance of the forces on the aircraft. To prevent or reduce these tendencies, the designers can suit the stability and the maneuverability of a particular type of aircraft to the purpose for which it is being designed. For example, a heavy patrol plane must be very stable, while a fighter aircraft must have great maneuverability. In the case of the heavy patrol plane, maneuverability is sacrificed for stability.

AIRCRAFT STABILITY

Stability may be defined as that characteristic of an aircraft which tends to cause it to fly (hands off) in a straight and level flightpath without control from the pilot. A stable aircraft holds or tends to hold a normal flightpath without control from the pilot. The unstable aircraft, on the other hand, must be brought to and held at the desired attitude of flight by the pilot.

Longitudinal Stability

When an aircraft has a tendency to keep a constant angle of attack with reference to the relative wind—that is, when it does not tend to put its nose down and dive or lift its nose and stall—it is said to have longitudinal stability. Longitudinal stability refers to the ability to resist pitching motion. The horizontal stabilizer is the primary surface which controls longitudinal stability. The action of the stabilizer depends upon the speed and angle of attack of the aircraft.

Under certain conditions of speed, load, and angle of attack, the flow of air over the stabilizer creates a force which pushes the tail up or down. When conditions are such that the airflow creates equal forces up and down, the forces are said to be in equilibrium. This condition is usually found in level flight in calm air.

Directional Stability

Stability about the vertical axis is referred to as directional stability. The aircraft should be designed so that when it is in straight and level flight it remains on its course heading even though the pilot takes his hands and feet off the controls. If an aircraft recovers automatically from a skid, it has been well designed and possesses good directional balance. The vertical stabilizer is the primary surface which controls directional stability.

Sweptback wings aid in directional stability. If the aircraft yaws from its direction of flight, the wing which is farther ahead offers more drag than the wing which is aft. The effect of this drag is to hold back the wing which is farther ahead, and to let the other wing catch up.

Directional stability is also obtained by a large vertical fin and a long fuselage.

Lateral Stability

We have seen that pitching is motion about the aircraft's lateral (athwartship) axis and yawing is motion about its vertical axis. Motion about its longitudinal (fore and aft) axis is a lateral or rolling motion. The tendency to return to the original attitude from such motion is called lateral stability.

A yawing motion produces a rolling motion, because one wing moves forward and gains lift, while the other wing moves backward and loses lift. A sideslip tends to produce both a rolling and a yawing motion. The yawing should be such as to turn the aircraft into the direction in which it is slipping. This is sometimes called directional stability. The fuselage alone is unstable, and therefore a vertical tail is needed. Usually there is a fixed fin and a rudder hinged to it.

CONTROL

Control is the action taken by the pilot to make the aircraft follow any desired flightpath. When an aircraft is said to be controllable, it is meant that the craft responds easily and promptly to movement of the control levers.

To understand how a pilot controls the aircraft, you, as an Airman, should understand the function and movement of the control surfaces. Different control surfaces are used to control the aircraft about each of the three axes. Moving the control surfaces on an aircraft changes the airflow over the aircraft's surface. This, in turn, creates changes in the balance of forces acting to keep the aircraft flying straight and level.

Controlling Around the Longitudinal Axis

The motion of the aircraft about the longitudinal axis is called rolling or banking. The ailerons (fig. 3-8) are used to control this movement.

The ailerons form a part of the wing and are located in the trailing edge of the wing toward the tips. The ailerons are the movable surfaces of an otherwise fixed surface wing. The aileron

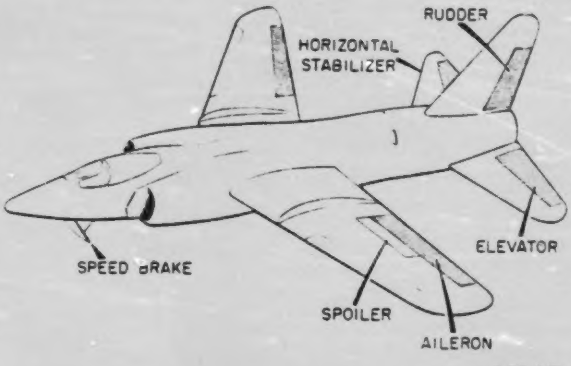


Figure 3-8.—Control surfaces of an aircraft.

is in neutral position when it is fitted flush into the trailing edge of the wing. The aileron which is raised decreases the lift of the wing causing it to drop, while the aileron which is lowered increases the lift of the wing, causing it to move up. The faster the rate of turn desired by the pilot, the steeper the aircraft must be banked.

The spoilers (fig. 3-8) are small plates fitted to the upper surface of the wings. The purpose of the spoilers is to disturb the smooth airflow across the top of the airfoil thereby creating an increased amount of drag and a decreased amount of lift on that airfoil.

Control Around the Vertical Axis

Turning the nose of the aircraft causes the aircraft to rotate about its vertical axis. Rotation of the aircraft about the vertical axis is called yawing. This motion is controlled by using the rudder.

The rudder (fig. 3-8) is a movable control surface attached to the trailing edge of the vertical stabilizer. When the pilot wishes to turn the aircraft to the right, he moves the rudder to the right. The area of the rudder protrudes into the airstream, causing a force to act on it. This is the force necessary to give a turning movement about the center of gravity which turns the aircraft to the right. If the rudder is moved to the left, it induces a counterclockwise rotation and the aircraft similarly turns to the left. The rudder can also be used in controlling a bank or turn. The main function of the rudder is to turn the aircraft in flight.

This turn is maintained by side pressure of the air moving past the vertical surfaces. When an aircraft begins to slip or skid, the pilot begins to apply rudder pressure to keep the aircraft heading in the desired direction (balanced).

Slip or sideslipping refers to any motion of the aircraft to the side and downward toward the inside of a turn. Skid or skidding refers to any movement upward and outward away from the center of a turn.

Control Around the Lateral Axis

When the pilot raises or lowers the nose of an aircraft, he is rotating the aircraft about its lateral axis. Elevators (fig. 3-8) are the movable control surfaces that cause this rotation about the lateral axis. They are normally hinged to the trailing edge of the horizontal stabilizer.

The elevators enable the pilot to make the aircraft climb or dive and also to obtain sufficient lift from the wings to keep the aircraft in level flight at various speeds.

The elevators are hinged surfaces that can be moved by the pilot to move either up or down. If the elevator is rotated up, it decreases the lift force on the tail causing the tail to lower and the nose to rise. If the elevator is rotated downward, it increases the lift force on the tail causing it to rise and the nose to lower. Lowering the aircraft's nose increases forward speed and raising the nose decreases forward speed.

For high-performance aircraft another means of stabilized control is the movable horizontal stabilizer, sometimes called the "flying tail." The horizontal stabilizer (fig. 3-8) is hydraulically actuated. When the control stick is moved, the complete stabilizer (the elevator being locked in the neutral position) is raised or lowered. This system affects flight the same as the elevator, except the amount of control surface is much larger, requiring only small movements to produce large effects.

Ailerons

Movement around the longitudinal axis (rolling) is controlled by the ailerons, which respond to side pressure applied to the control stick. Pressure applied to the stick toward the left raises the left aileron and lowers the right aileron, causing the aircraft to bank to the left. The ailerons are linked together by control cables so that when one aileron is down, the opposite aileron is up. The wind strikes the obstructing surfaces raising the wing whose aileon is down, lowering the wing whose aileron is up, thus literally twisting the aircraft around its longitudinal axis.

Flaperons

The flaperons are control surfaces used by some high-performance aircraft. The flaperon is a combination of a flap and an aileron. The operation of the flaperon affects flight either as a flap to increase lift and drag, used

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for takeoff and landing; or as an aileron for controlling the aircraft around the longitudinal axis.

Tabs

Even though an aircraft has inherent stability, it does not always tend to fly straight and level. The weight of the load and how it is placed in an aircraft affect its stability. Various speeds also affect its flight characteristics. If the fuel in one wing tank is used before the other wing tank, the aircraft tends to roll toward the full tank. All these variations require a pilot to exert pressure on the controls to correct for them.

While climbing or gliding, it is necessary to exert pressure to keep the aircraft in the desired attitude. Such constant control pressure is very tiring for the pilot.

To offset the forces that tend to unbalance the aircraft in flight, ailerons, elevators, and rudders are provided with auxiliary controls known as tabs. These are small, hinged control surfaces attached to the trailing edge of the primary control surfaces. They can be moved up or down by means of a crank or moved electrically from the cockpit. These tabs can be used to balance the forces on the controls so that the aircraft flies straight and level, or may be set so that the aircraft maintains either a climbing or gliding attitude. (This allows the pilot more freedom of movement.)

TRIM TABS.–Trim tabs are either controlled by the pilot in the cockpit or adjusted on the ground before taking off. Trim tabs are located on elevators, rudders, and ailerons. An aileron trim tab is shown in figure 3-9.

SPRING TABS.–Spring tabs are similar in appearance to trim tabs, but serve an entirely different purpose. Spring tabs are used for the same purpose as hydraulic actuators; that is, to aid the pilot in moving a primary control surface.

On the P-2 aircraft, a spring tab is hinged to the trailing edge of each aileron just outboard of the aileron trim tab. The spring tab is actuated by a spring-loaded push-pull rod assembly which is also linked to the aileron control linkage. The linkage is connected in such a way that movement of the aileron in one direction causes the spring tab to be deflected in the opposite direction. This provides a balanced condition, thus reducing the amount of force required by the pilot to move the ailerons.

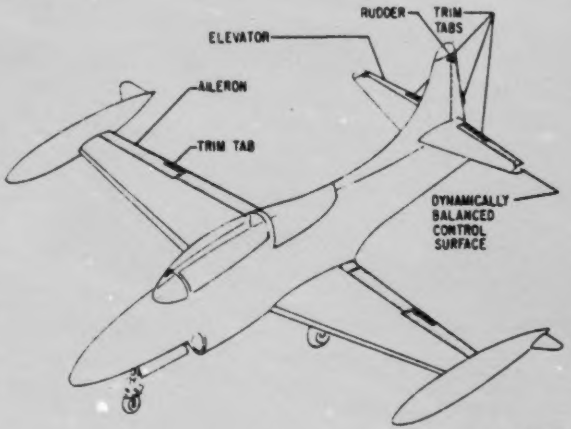

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Figure 3-9.–An aileron trim tab.

The deflection of the spring tabs is directly proportional to the aerodynamic load imposed upon the aileron; therefore, at low speeds the spring tab remains in a neutral position and the aileron is a direct manually controlled surface. At high speeds, however, where the aerodynamic load is great, the tab functions as an aid to the pilot in moving the primary control surface. Spring tabs are referred to by some manufacturers as balance tabs, others may call them servo tabs.

Speed Brakes

Speed brakes are hinged, movable control surfaces used for slowing down the speed of an aircraft by increasing drag. Some manufacturers refer to them as dive brakes, others call them dive flaps. On some aircraft (fig. 3-8) they are hinged to the lower surface of the fuselage, on others they are attached to the wings. Regardless of their location, speed brakes serve the same purpose on all aircraft on which they are used. Their primary purpose is to keep the speed from building up too high in dives and descents. They are also used in slowing down the speed for landing. Speed brakes are operated hydraulically or electrically.

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High Lift Devices

High lift devices are used in combination with airfoils in order to reduce the takeoff or landing speed by changing the lift characteristics of an airfoil during the landing or takeoff phases. When these devices are no longer needed they are returned to a position within the wing to regain the normal characteristics of the airfoil.

Two high lift devices commonly used on aircraft are shown in figure 3-10. One of these is known as a slot, and is used as a passageway through the leading edge of the wing. At high angles of attack the air flows through the slot and smooths out the airflow over the top surface of the wing. This enables the wing to pass beyond its normal stalling point without stalling. Greater lift is also obtained.

The other device is known as a flap, which is a hinged surface on the trailing edge of the wing. The flap is controlled from the cockpit, and when not in use it conforms to the trailing edge of the wing. The use of flaps increases the lift of the wing, making it possible for the speed of the aircraft to be decreased without stalling. This also permits a steeper gliding angle to be obtained as in the landing approach. The flaps are primarily used during takeoff and landing.

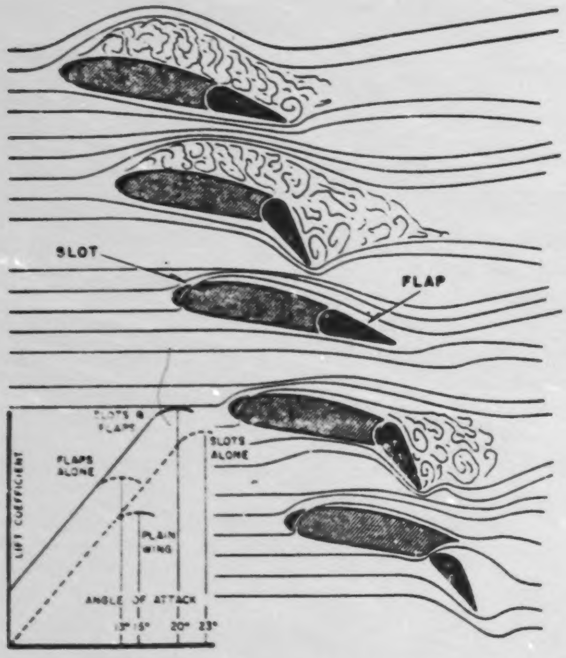

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Figure 3-10.–High lift devices.

Variable Incidence Wings

The variable incidence wing is an aircraft's wing whose leading edge can be raised during the landing and takeoff phases. This action allows the angle of attack and angle of incidence to vary simultaneously reducing the amount the nose of the aircraft must be raised to produce the required angle of attack. This aids the pilot's visibility during landings and takeoffs.

The angle of incidence is the angle between the chord of an airfoil and the longitudinal axis of an aircraft. Normally, the wing is approximately parallel to the longitudinal axis of the aircraft and flight control is accomplished by using flaps, elevators, ailerons, and aircraft attitude.

In order to make a good landing, an aircraft must be held in a glide until it is near the ground and then a smooth transition to landing attitude made. Since the power is normally reduced, speed is decreasing and the tail must be lowered to increase the angle of attack to compensate for the loss in speed. As the speed decreases, the pilot compensates by raising the nose of the aircraft or raising the variable incidence wing, increasing the angle of attack, and thus increasing the lift. As the aircraft continues to decelerate, the pilot increases the angle of attack until the proper landing attitude is achieved.

Boundary Layer Control Devices

Slats are movable control surfaces attached to the leading edge of the wing. When the slat is closed, it forms the leading edge of the wing. When in the open position (extended forward), a slot is created between the slat and the wing leading edge. Thus, high-energy air is introduced into the boundary layer over the top of the wing. At low airspeeds this improves handling characteristics, allowing the aircraft to be controlled laterally at airspeeds below the otherwise normal landing speed. This is known as "boundary layer control." Boundary layer control is intended primarily for use during

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operations from carriers; that is, for catapult takeoffs and arrested landings.

Boundary layer control can also be accomplished by directing highpressure engine bleed air through a narrow orifice located just forward of the wing flap leading edge. This directs a laminar flow (air in layers) of air over the wing and flaps when the flaps have opened sufficiently to expose the slats. The high temperature and high velocity laminar air passing over the wing and flaps delay flow separation (the airstream over an airfoil no longer follows the contour of the airfoil), hence reduces turbulence and drag. (See fig. 3-10.) This results in a lower stall speed and allows slower landing speeds.

Area Rule

Area rule is a prescribed method of design for obtaining minimum zero lift drag for a given aerodynamic configuration, such as the wing and fuselage designed for certain speeds. For an aircraft designed to fly at transonic speeds, the area rule is applied by varying the cross sectional area of the fuselage at various points along the length of the fuselage. An example of the rule is the F-4J aircraft whose fuselage design allows the aircraft to approach an ideal body of minimum drag.

HELICOPTERS

The main difference between a helicopter and a fixed-wing aircraft is the main source of lift. The fixed-wing aircraft derives its lift from a fixed airfoil surface while the helicopter derives lift from a rotating airfoil called the rotor. Aircraft are classified as either fixed wing or rotating wing. The word helicopter comes from the Greek words meaning "helical wing" or "rotating wing."

The flight characteristics are dependent upon the forward speed and the control surface movements for a fixed-wing aircraft; in a helicopter flight characteristics are determined by the rotational speed and pitch variations of the rotor blades. Since its flight characteristics are independent of forward speed, a helicopter is able to move in any direction at a controlled low speed and still remains safely airborne. The engine-rotor dual tachometer and the manifold pressure gage become the principal flight instruments, for piston engine powered helicopters, especially during hovering and low-speed flight, when adequate rotor speed must be kept up in order to maintain lift and controllability.

While there may be no need for flight other than in the forward direction, it may be necessary to hover in crosswinds and tailwinds. The helicopter is directionally stable in forward flight, but in sideward and rearward flight directional control is more difficult to maintain. This is because the nose of the helicopter has a tendency to turn in the direction of flight.

There are several theories advanced on the lift of rotor blades. According to the blade element theory, the airflow over any airfoil section or blade element of the rotor blade acts just as it does on a fixed wing. The total lift is arrived at by integrating or summing up the lift of the individual blade elements over the length of the blade and then adding the lift of each blade together. In the case of a rotor, the fact that the velocity at each element is different and that there may be differences in angle of attack makes this a more complicated problem.

If the rotor is operating in a hovering condition with no wind, the plane of rotation is parallel to the ground. This makes the local relative wind parallel to the ground and also the angle of attack on any blade element is the same throughout the cycle of rotation. The lifting force is perpendicular to the plane of rotation.

If the helicopter is rising, there is a component of velocity parallel to the axis of the rotor, and the relative wind is then a resultant of the rotational velocity of the airfoils and the vertical velocity of the helicopter. Since lift is considered to act perpendicular to the relative wind and the relative wind is no longer parallel to the plane of rotation, the lift is not acting perpendicular to the plane of rotation. The vertical thrust (the force acting to overcome gravity) is slightly less than the lifting force.

Many factors determine the amount of lift available in helicopter operation. Generally speaking, the pilot has control of two of these. One is the pitch angle of the rotor blades; the other is the power delivered to the rotor. By controlling the pitch angle of the rotor blades, the pilot can establish the vertical flight of the helicopter. By manipulating the engine speed, the pilot maintains the desired amount of lift of the aircraft regardless of the increase or decrease in blade pitch.

The cyclic pitch control is similar to the control stick of a conventional aircraft. It acts through a mechanical linkage to cause the pitch of each main rotor blade to change during a cycle of rotation. The rapidly rotating rotor blades create a disk area that can be tilted in any direction with respect to the supporting rotor mast. Horizontal flight is controlled by changing the direction of tilt of the rotor disk to produce a force in the desired direction.

Helicopters vary in size, complexity, and assigned mission. An example is the Navy's helicopter, model SH-3A. (See fig. 3-16.) This is a twin-engine, all-weather, antisubmarine warfare (ASW) helicopter. The crew consist of a pilot, copilot, sonar operator, and relief sonar operator. It is designed for land- and carrier-based operations and is capable of water landings and takeoffs.

DESIGNATION OF NAVAL AIRCRAFT

The present system of designating naval aircraft was initiated in late 1962. This system applies to all United States military aircraft. All the aircraft designations have one thing in common–a hyphen. The letter just before the hyphen specifies the basic mission or type of the aircraft. The letters and their basic missions are as follows:

A–Attack.
B–Bomber.
C–Cargo/transport.
E–Special electronic installation.
F–Fighter.
H–Helicopter.
K–Tanker.
O–Observation.
P–Patrol.
R–Reconnaissance.
S–Antisubmarine.
T–Trainer.
U–Utility.
V–VTOL and STOL.
X–Research.
Z–Airship.

If the aircraft has been modified from its original mission, a letter in front of the basic mission letter indicates its modified mission. Mission modification letters are as follows:

A–Attack.
C–Cargo/transport.
D–Director (for controlling drone aircraft or missiles).
E–Special electronic installation.
H–Search/rescue.
K–Tanker.
L–Cold Weather aircraft (for Arctic or Antarctic operations).
M–Missile carrier.
Q–Drone.
R–Reconnaissance.
S–Antisubmarine.
T–Trainer.
U–Utility.
V–Staff.
W–Weather.

A number after the hyphen specifies the design number of the aircraft. A letter other than A (A being the original design) after this number indicates a change in the original design of the aircraft.

For example, the A in A-3B means an attack aircraft. Its design number is three, and it has been modified one time, which is represented by the B (second letter of the alphabet). If the A-3B is modified to perform early warning missions, it becomes the EA-3B.

Another letter may appear before the basic mission letter other than the mission modification letter. It indicates the aircraft's special use or status. To eliminate confusion, all special use letters are different from the modified mission letters. Special use letters are as follows:

G–Permanently grounded (utilized for instruction and training).
J–Special test, temporary (after test, the aircraft will be returned to original or standard operational configuration).
N–Special test, permanent (configuration is too drastically changed by the test for the aircraft to be returned to original configuration).
X–Experimental (developmental stage in which basic mission has not been established).
Y–Prototype (only a few procured for development of design).

Z–Planning (used for identification during planning).

If both the special use letter and the modified mission letter apply to the same aircraft, the special use letter comes first. For example, YEP-2E refers to a prototype (Y), early warning (E), patrol aircraft (P), design number 2, and the design has been modified five times.

Table 3-1 gives the basic mission, design number, manufacturer, and popular name of naval aircraft.

Table 3-1.–Naval aircraft.

Basic mission and design number	Manufacturer	Popular name
A-1	Douglas	Skyraider
A-3	Douglas	Skywarrior
A-4	Douglas	Skyhawk
A-5	North American	Vigilante
A-6	Grumman	Intruder
A-7	Ling-Temco-Vought	Corsair II
C-45	Beech	Navigator
C-47	Douglas	Skytrain
C-54	Douglas	Skymaster
C-118	Douglas	Liftmaster
C-119	Fairchild	Packet
C-121	Lockheed	Warning Star
C-130	Lockheed	Hercules
C-131	Convair	Samaritan
C-140	Lockheed	Jet Star
C-1	Grumman	Trader
E-1	Grumman	Tracer
E-2	Grumman	Hawkeye
F-4	McDonnell	Phantom II
F-6	Douglas	Skyray
F-8	Chance Vought	Crusader
F-9	Grumman	Cougar
F-10	Douglas	Sky Knight
H-1	Bell	Iroquois
H-2	Kaman	Seasprite
H-3	Sikorsky	Sea King
H-13	Bell	Sioux
H-19	Sikorsky	Chickasaw
H-34	Sikorsky	Sea horse or Seabat
H-43	Kaman	Huskie
H-46	Boeing Vertol Div.	Sea Knight
H-50	Gyrodyne	Dash
H-53	Sikorsky	Seastallion
O-1	Cessna	Bird Dog
P-2	Lockheed	Neptune
P-3	Lockheed	Orion
S-2	Grumman	Tracker
T-1	Lockheed	Sea Star
T-2	North American	Buckeye
T-28	North American	Trojan
T-29	Convair	Flying Classroom
T-33	Lockheed	Shooting Star
T-34	Beech	Mentor
T-39	North American	Saberliner
U-1	DeHavilland	Otter
U-11	Piper	Aztec
U-16	Grumman	Albatross

THE NAVY'S AIRCRAFT

In each major type–fighter, attack, patrol, and transport–the Navy has aircraft far superior to those flown in past years. The Navy is constantly seeking better and more advanced aircraft operational capabilities. Manufacturers are aware of this and are constantly developing products to meet these demands. Some combat aircraft are described in the following paragraphs.

McDONNEL PHANTOM II, F-4 SERIES

The F-4 is a twin-engined, two-place, all-weather jet aircraft. It is used principally by the Navy as a fighter, but is also used as a reconnaissance aircraft.

The crew consists of a pilot and a radar observer, and they are in tandem cockpits (one forward and one aft). The principal recognition features are the sweptback wings with sawtooth leading edges and tip dihedral and a sweptback empennage. It is designed for land- and carrier-based operation with catapult provisions and arresting gear. The wings incorporate folding wingtips. This aircraft is powered by two General Electric J79 engines with afterburners. (See fig. 3-11.)

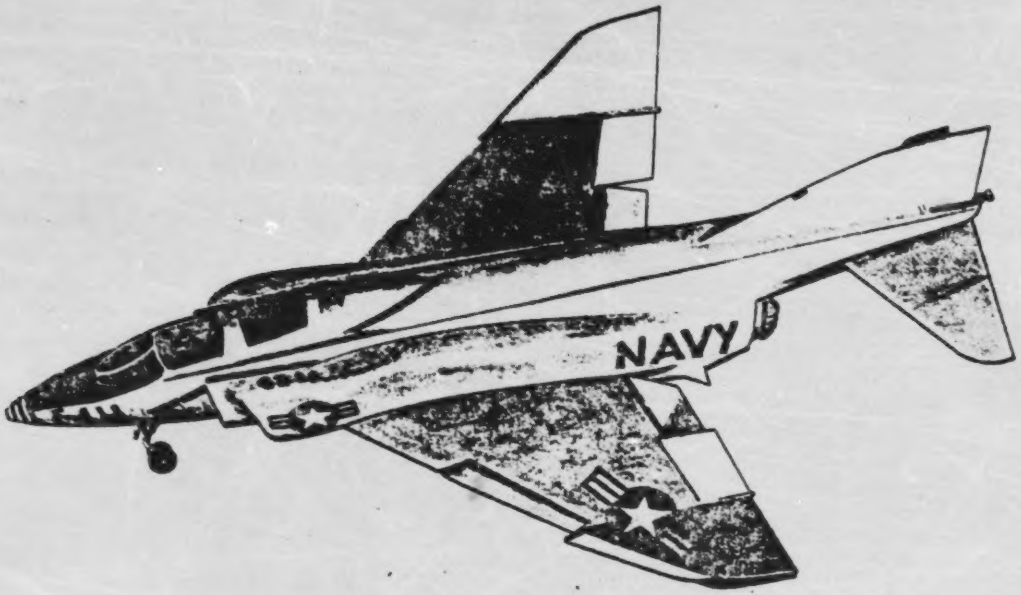

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Figure 3-11.–The McDonnell Phantom II, F-4.

GRUMMAN INTRUDER, A-6 SERIES

The A-6 is a carrier-based, two-place jet aircraft that is capable of good performance in low level operations. When used as an attack aircraft, an electronic attack navigation system is employed that permits delivery of weapons to targets that are completely obscured by weather or darkness. A tailpipe downward tilting device permits the use of shorter distance for takeoffs and landings; this provides better capabilities for operations from carriers. The A-6 can carry a heavier and more varied weapons load than any other Navy attack aircraft. The midwing and horizontal stabilizer have a moderate sweepback. The bubble type canopy is placed forward of the wing, providing the pilot with good visibility.

A distinguishing recognition feature is the relatively small size of the fuselage between wing and tail in comparison to the size of the fuselage forward of the wing. This aircraft has been configured and used for electronic countermeasures where its outstanding endurance is a favorable factor. (See fig. 3-12.) It is powered by two Pratt & Whitney turbojet engines.

LING-TEMCO-VOUGHT (LTV) CORSAIR II, A-7 SERIES

The A-7 is a single-place, lightweight, carrier-based, single-engine aircraft, at present used only for attack purposes. It is equipped with the latest electronic navigation, target identification, weapons delivery, and communications equipment. It is powered by a Pratt & Whitney turbofan engine without afterburner. The wing is placed midway back and high on the fuselage, with moderate sweepback. The air inlet for the engine is on the underside of the nose with the cockpit canopy above it. The aft fuselage appears fat and the vertical stabilizer large. The A-7 has folding wingtips for closer parking aboard carriers. (See fig. 3-13.)

LOCKHEED NEPTUNE, P-2 SERIES

The P-2 is a land-based aircraft that has been used by the Navy for varied missions. At present it is used for antisubmarine warfare (ASW) and for reconnaissance. The aircraft is powered by two Curtis Wright air-cooled reciprocating and two Westinghouse turbojet

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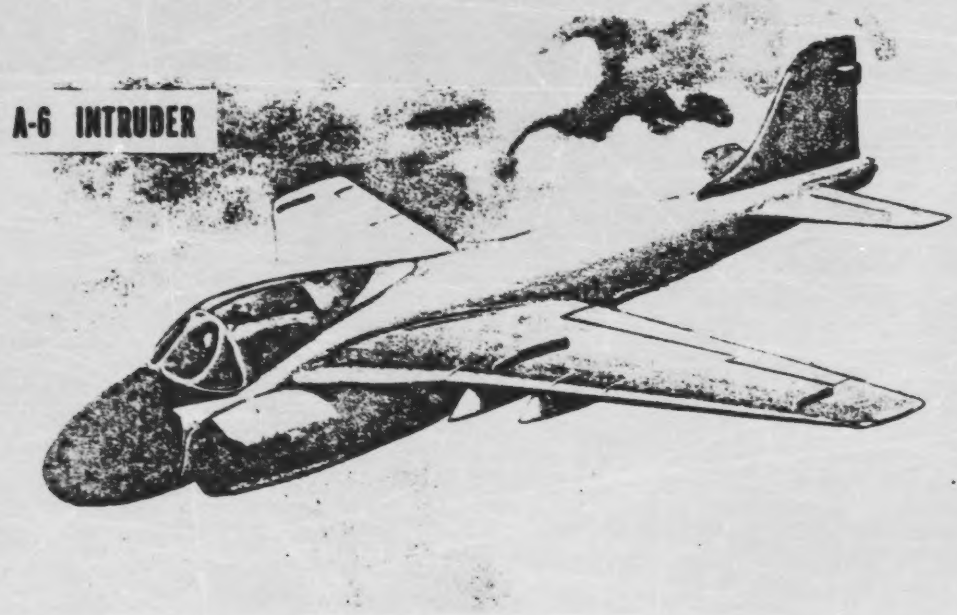

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Figure 3-12.–Grumman Intruder, A-6.

engines, the jets being mounted on pods under the wing and outobard of the recirprocating engines. The ASW crew usually numbers 10 men. The aircraft has a midwing with but little sweepback and has tip tanks containing searchlight and radar, a very high vertical stabilizer, a bulging cockpit canopy, a clear plastic nose, and a cone extending from the rear of the tail containing Magnetic Anomaly Detection (MAD) equipment. This aircraft is being

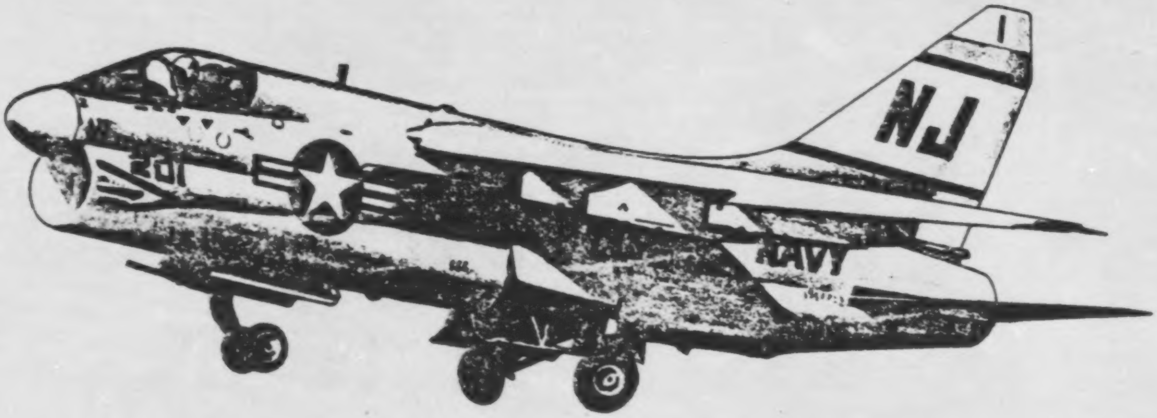

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Figure 3-13.–Ling-Temco-Vought Corsair II, A-7.

replaced by the P-3 and is no longer in production but many squadrons continue to operate with them. (See fig. 3-14.)

LOCKHEED ORION, P-3 SERIES

The P-3 Orion (fig. 3-15) is a land-based ASW aircraft which represents advancements stemming from the Navy's antisubmarine research and development program over the last several years.

It is the world's most complete airborne antisubmarine detection system. The C version has the A-NEW data processing system which utilizes a high-speed digital computer for assimilating information from both the aircraft's submarine detection sensors and a memory bank. The system display provides a readout of tactical ASW detection information to the operator.

It is powered by four Allison turboprop engines. The cabin is air conditioned and pressurized and is equipped with bunks and a galley. Normally, a crew of 10 is needed for ASW operations. Included in its armament are depth charges, torpedoes, and rockets.

SIKORSKY SEA KING, SH-3 SERIES

The SH-3 is a twin-engine helicopter used primarily for antisubmarine warfare, but also used for mine countermeasures and transportation. It is manufactured by the Sikorsky Aircraft Division of United Aircraft Corporation.

The crew consists of a pilot, copilot, sonar operator, and relief sonar operator. Designed for land and carrier ASW operations, the A model incorporates automatic folding of the rotary wing blades and a folding pylon. In addition to the sonar detection equipment, it is

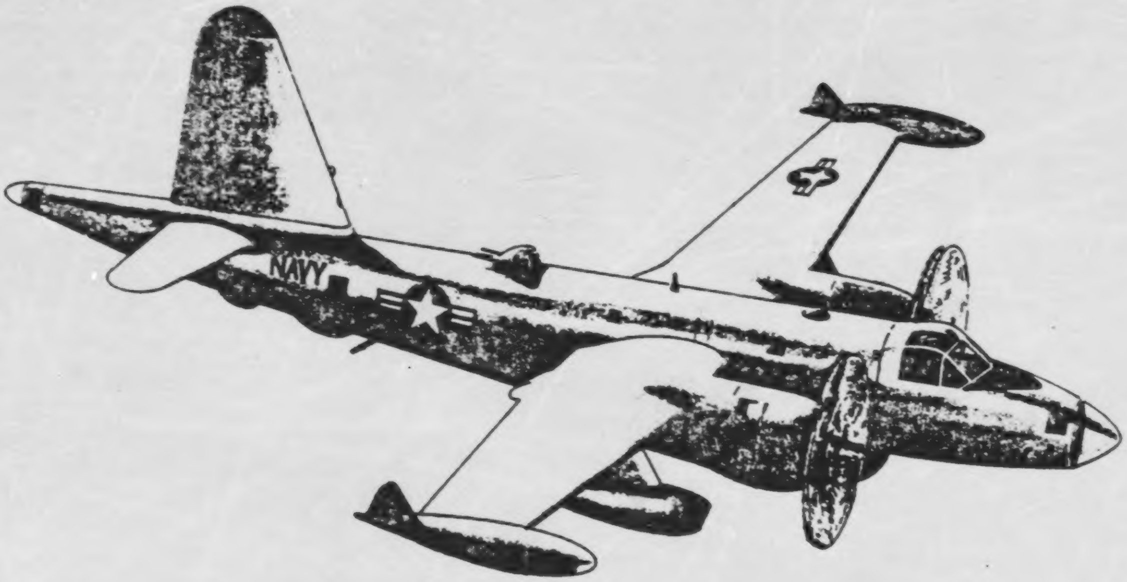

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Figure 3-14.–Lockheed Neptune, P-2.

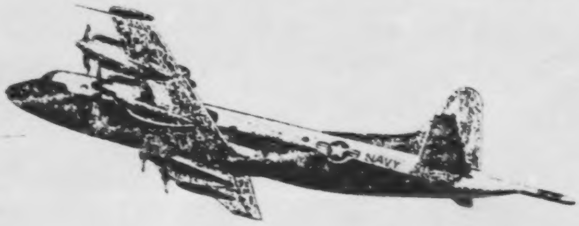

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Figure 3-15.–The Lockheed Orion, P-3.

equipped with an automatic hovering device. It is capable of water landing and takeoff.

Distinguishing features include a hull-shaped fuselage and outrigger sponsons into which the main landing gear retracts. (See fig. 3-16.)

A fixed horizontal stabilizer is installed on the upper right side of the pylon and two General Electric gas turboshaft engines are mounted side by side above the fuselage forward of the rotor head.

The SH-3A has three separate hydraulic systems and a variety of electric and electronic equipment.

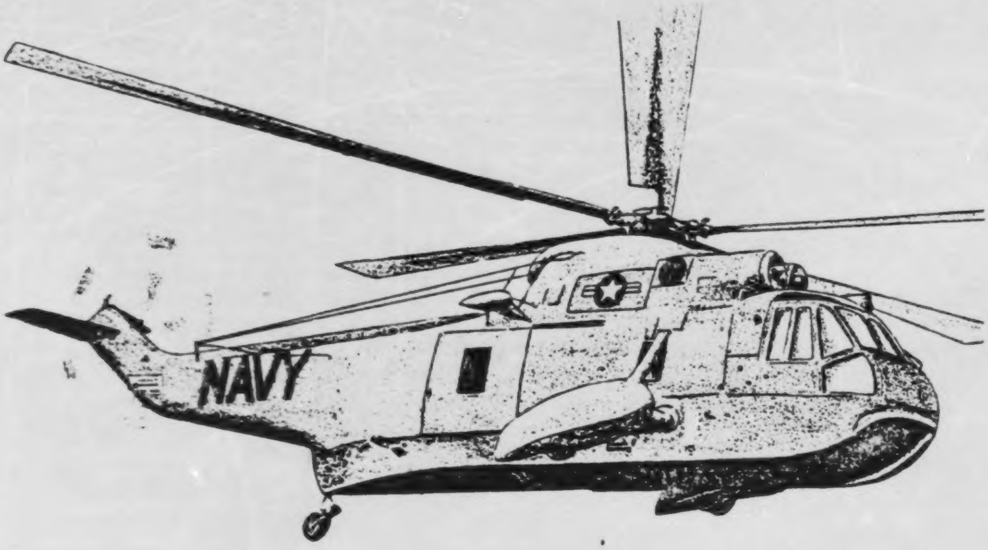

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Figure 3-16.–The Sikorsky Sea King, SH-3.

CHAPTER 4

AIRCRAFT STRUCTURES AND CONTROL SYSTEMS

Each aircraft is built to meet certain specified requirements. These standards must be selected in such a way that they can all be incorporated into one machine. In other words, it is not possible to have any one aircraft possess the speed of a racer, the lightness of a sailplane, the comfort of a passenger transport, and the maneuverability of a fighter. The type and class of an aircraft determine how strong it is to be built. A Navy fighter, for example, must be fast, maneuverable, and equipped for both attack and defense. To meet these requirements, it is highly powered and has a very strong structure.

STRUCTURAL REQUIREMENTS

There are various demands which an efficient aircraft must meet. The two most important demands in the structure are strength and lightness. The Golden Gate Bridge and the Empire State Building were constructed to withstand loads much greater than the heaviest burden they will ever have to support. This principle cannot be followed in an aircraft because of weight limitations, yet the designer must see that enough strength is built into the craft to withstand any maneuver it may be called on to make. To obtain such combined strength and lightness, each load or stress imposed upon an aircraft must be carefully analyzed and considered in its designing. Such a determination of loads is called a stress analysis.

A great many factors cause forces to act on various aircraft parts. The weight of the craft itself produces gravity forces. Any maneuver which causes acceleration or increase in the angle of attack causes large forces on the wings. The tail surfaces affecting the balance of the craft are the main forces acting on the fuselage. The landing gear supports the gravity forces when it is on the ground, and takes the extra forces caused by takeoff and landing.

Stresses are the reacting forces set up in aircraft structures due to the external forces brought to bear on the structures. There are five principal kinds of stress, usually measured in pounds per square inch (psi). These stresses are known as tension, compression, shear, bending, and torsion. These are illustrated in figure 4-1.

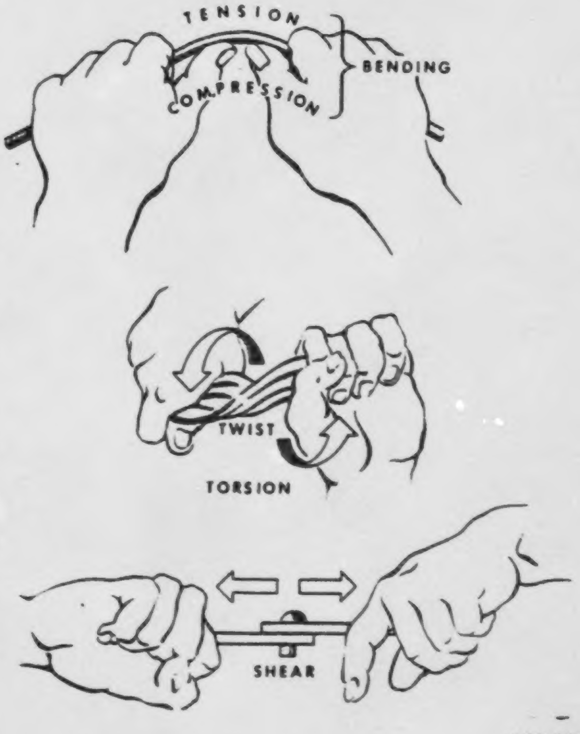

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Figure 4-1.–Five types of stresses.

TENSION

Tension may be defined as "pull." It is a stress caused by stretching or pulling at the ends of an object. An elevator cable is in tension when the pilot moves the control column. Therefore, tension is the resistance to pulling apart or stretching, produced by two forces pulling in opposite directions along the same straight line. The cables of a control system may be placed under tension by the pilot, when he operates the controls.

COMPRESSION

If forces acting on an aircraft move toward each other to squeeze the material, then the stress is called compression. This is just the opposite of tension. Where tension is described as a "pull," compression might be defined as a "push." Compression is the resistance to pushing together or crushing, produced by two forces pushing toward each other in the same straight line. The landing gear struts of an aircraft while on the ground are under compression.

SHEAR

Cutting a piece of paper with a pair of scissors is a simple example of shearing action. As the blades of the scissors close, the paper is cut by a shearing action between the blades. Shear in an aircraft structure is a stress exerted when two pieces of material, fastened together, tend to be separated by sliding one over the other, each part in an opposite direction. In general, the rivets in an aircraft are subjected to shear, and bolts are usually subjected to both shear and tension.

BENDING

A combination of tension and compression is known as bending stress. This is caused by the simple bending of an object. A simple illustration of bending is that of a beam supported at each end with a load hung from its center. The load causes the beam to sag at the center. This sagging stretches the fibers on the lower surface and compresses those on the upper surface. Thus, the bending causes tension in the lower portion of the beam and compression in the upper portion. The wing spars of aircraft in flight are subjected to bending stresses.

TORSION

Torsional stresses are the results of a twisting force or motion. When you wring out a chamois skin, you are putting it under torsion. In aircraft, many elements of the flight control system are in torsion. Torsion is produced in an engine crankshaft, while the engine is running.

Forces which cause torsional stresses produce torque.

LIMITS OF STRESS

All materials are somewhat elastic. A rubberband is extremely elastic, while a piece of metal, comparatively, is not very elastic.

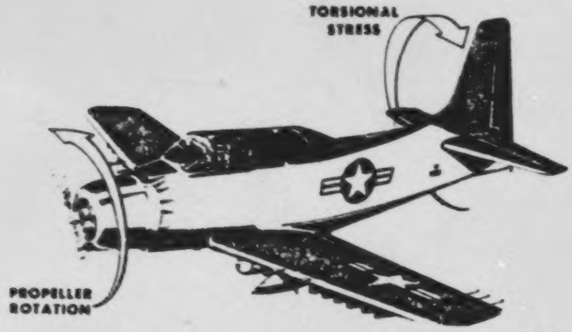
All the structural members of an aircraft are subjected to one or more stresses. Sometimes a member has alternate stresses; that is, it is under compression one instant and tension the next. Therefore, the strength of aircraft materials must be great enough to withstand the maximum stress of any sort which may be brought to bear.

SPECIFIC ACTION OF STRESSES

It is very important that you understand the stresses encountered on the main parts of an aircraft. A knowledge of these basic stresses on the structures makes meaningful the work you perform in naval aviation, particularly when making preflight or periodic inspections.

The fuselage of the aircraft is subjected to four types of stress—torsion, bending, tension, and compression.

Torsional stress in a fuselage are created in several ways. The most common way this stress is encountered is in engine torque. Engine torque tends to rotate the aircraft in the direction opposite to that which the propeller is turning; and it is this reaction which creates a torsional stress in the fuselage. This is illustrated in figure 4-2. Torsional stresses are created in the fuselage by action of the ailerons when the aircraft is maneuvered, by gusts of wind striking the wings while the aircraft is in flight, and when a wheel strikes rough ground while taxiing.



AN.27

Figure 4-2.–Engine torque creates torsional stress in aircraft fuselages.

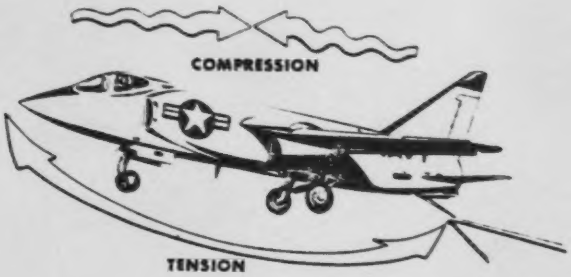


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Figure 4-3.–Bending action occurring upon carrier landing.

When an aircraft is at rest on the ground, there is a bending action on the fuselage due to the weight of the craft itself. This bending action is greatly increased when the aircraft makes a carrier landing. This bending action creates a tension stress on the lower skin of the fuselage, and a compression stress on the top skin of the fuselage as may be seen in figure 4-3. These stresses also occur in the fuselage when the aircraft is in flight due to the reaction of the wind against the wings and empennage. While in flight, lift forces act upward against the wings, tending to bend them upward. They are prevented from folding over the fuselage by the resisting strength of the wing structure. This bending action creates a tension stress on the bottom of the wings and a compressive stress on the top of the wings.

MATERIALS OF CONSTRUCTION

An aircraft requires materials which must be both light and strong. Early aircraft builders started using wood; later, light metal alloys with greater strength than wood were developed and utilized. Materials currently used in aircraft construction may be classified as metallic and nonmetallic.

The most commonly used metals are steel, aluminum, magnesium, titanium, and their alloys. Alloy steels have been developed which are of much greater strength than those used generally in other fields of engineering. These steels contain small percentages of carbon, nickel, and chromium, and occasionally vanadium and molybdenum. High-tensile steels will stand stresses of 50 to 150 tons per square inch without failing. Such steels are used in making tubes, rods, and wires.

Another type of steel which is used extensively is stainless steel. This alloy resists the corrosion to which all metals are subjected. This alloy is particularly valuable for use in or near salt water.

Aluminum and aluminum alloys are used extensively in aircraft construction. Aluminum in its pure state is weak and is not employed in any part of the aircraft structure.

Far more important than aluminum are its alloys containing copper, manganese, magnesium, and silicon. These alloys are important because they are stronger than aluminum and have more uses in aircraft construction.

Magnesium is a metal lighter than aluminum. It is frequently used in aircraft structures, when alloyed with small quantities of manganese, zinc, copper, and silicon.

Titanium is a light, strong, corrosion-resistant metal, discovered 150 years ago, but only recently made suitable for aircraft use. Methods recently developed make titanium ideally suited for applications where aluminum alloys are too weak and stainless steel is too heavy. In addition, titanium is completely unaffected by long exposure to sea water and marine atmospheres.

In addition to the metals mentioned above, various types of plastic materials are used in aircraft construction. Transparent plastic is used in canopies and windshields. A relatively new material, called reinforced plastic, is being used more and more in the construction of flight control surfaces, stabilizers, radomes, and wingtips.

Transparent plastic surfaces must be handled with care since this material is relatively soft and is easily scratched. In addition, most transparent plastic softens when exposed to excessive heat and must therefore be treated accordingly. At approximately 225°F, transparent plastic becomes soft and very pliable.

Reinforced plastic is a sandwich type material, being made up of two outer facings and a center layer, called the core. The facings are made up of several layers of glass cloth, bonded together with a liquid resin. The core material consists of a honeycomb structure made of glass cloth, fabricated into a variety of cell sizes. Reinforced plastic is a strong material but light in weight. No special precautions are required in the routine care and maintenance of reinforced plastic surfaces.

PRINCIPAL STRUCTURAL UNITS

The principal structural units of an aircraft consist of the fuselage, wings, control surfaces, and landing gear. Figure 4-4 illustrates these units in a naval aircraft.

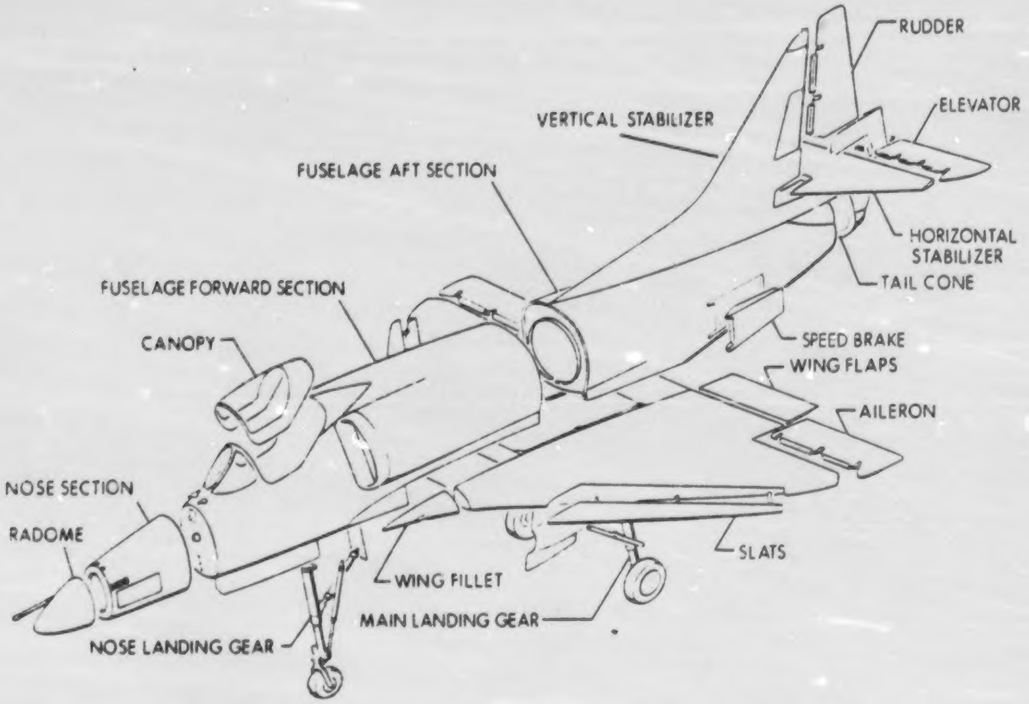
The term "right" or "left" used in relation to any of the structural units refers to the right or left hand of the pilot seated in the cockpit.

FUSELAGE

The fuselage is the main structure (or body) of the aircraft. The powerplant, wings, tail surfaces (empennage), and landing gear are attached to it. It houses the crew and cargo. Detail design depends upon the function and structural requirements of the aircraft.

Regardless of the attitude or position of an aircraft, there are always stresses on the fuselage structure. It must be constructed to withstand all such stresses.

There are two general types of fuselage construction, called truss and monocoque. The truss type construction uses a lattice type frame for the fuselage. This type construction is


RUDDER
ELEVATOR
VERTICAL STABILIZER
FUSELAGE AFT SECTION
HORIZONTAL STABILIZER
TAIL CONE
FUSELAGE FORWARD SECTION
SPEED BRAKE
WING FLAPS
CANOPY
AILERON
NOSE SECTION
RADOME
SLATS
WING FILLET
MAIN LANDING GEAR
NOSE LANDING GEAR

AN.29

Figure 4-4.–Principal structural units of a naval aircraft.

wholly inadequate to meet the needs of modern aircraft.

Monocoque

The work monocoque is a French expression meaning "one shell," which describes this type of fuselage. It is applied to the type of structure in which the strength is supplied by a single outside shell.

In the true monocoque structure, all stresses are carried by the shell. This is the ideal type of construction due to the fact that no internal bracing exists to interfere with control installations. The monocoque structure is suited for small, light aircraft where the shell is sufficiently small to take up the strains imposed upon it. Larger aircraft cannot use this type of structure due to the heavy skin which is required to withstand the loads. For this reason the semimonocoque structure was developed and put into use in modern aircraft.

The semimonocoque, shown in figure 4-5, is similar to the monocoque except that longitudinal stringers have been added to maintain the shape of the structure. These stringers carry the bending load and distribute the load evenly over the structure.

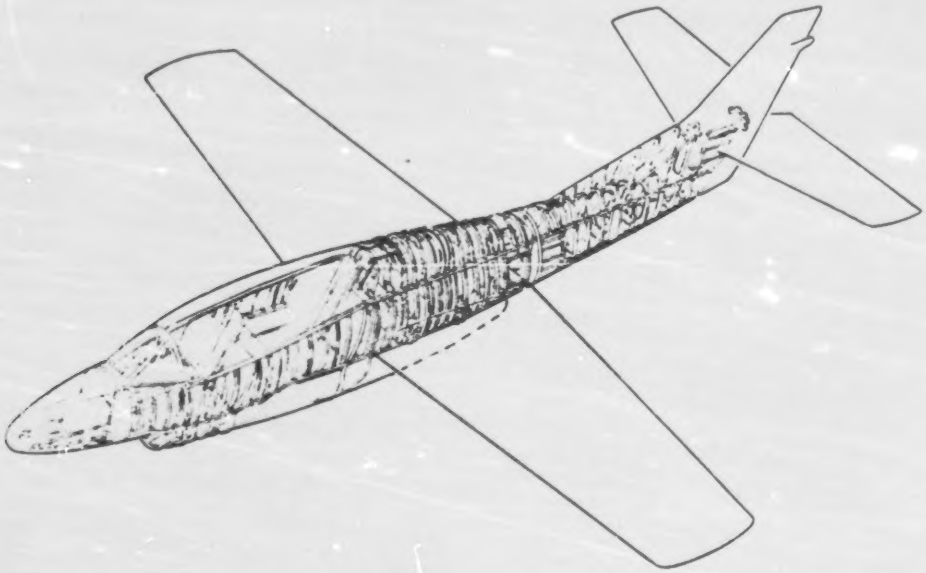
Semimonocoque fuselages are streamlined, fireproof, and unaffected by climatic conditions when proper protective coatings are applied.

Engine Mounts

Aircraft which have a single reciprocating engine have facilities for securing the engine to the front of the fuselage. Aircraft which have two or more engines have these facilities built into the aircraft wing in the form of nacelles. (A nacelle is an enclosed shelter for the powerplant.)

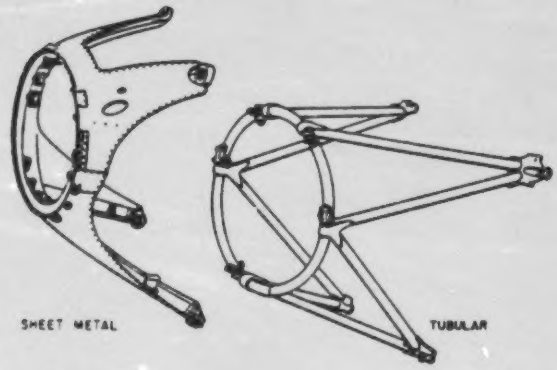
Since a particular type engine may be used on several types of aircraft, an adapter (or engine mount as it is commonly referred to) must be used to adapt an engine to an aircraft. The engine mount may be a welded tubular frame or a riveted structure (fig. 4-6). The size, type, and other characteristics of the engine determine the design of a mount.

Most jet engine mountings are two or more ring type mountings to which the engine is bolted. This makes the combined engine and fuselage the main strength of the aircraft and permits the engine to be removed for maintenance work.



AN.30

Figure 4-5.–Semimonocoque fuselage construction.


SHEET METAL
TUBULAR

AN.31

Figure 4-6.–Reciprocating engine mounts.

Station Numbering System

Various points on the fuselage are located by station numbers. Station 0 is usually located at or near the nose of the aircraft, and other stations are located at measured distances (in inches) aft of station 0.

A typical station diagram is shown in figure 4-7. On this particular aircraft, station 0 is located 16 inches forward of the nose. The fuselage break (for engine removal) is located at station 277.5.

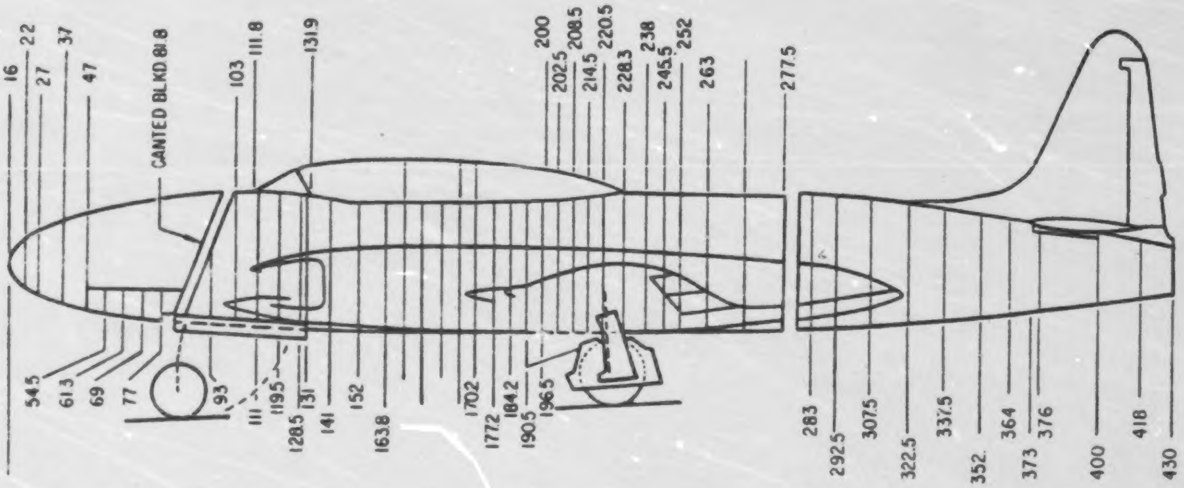
WINGS

The wings are designed to develop the major portion of the lift of a heavier-than-air-aircraft. Wing structures carry some of the heaviest loadings found in the aircraft structure; therefore, there are various details which the mechanic who performs the inspection, maintenance, and repair must understand. The Airman should be familiar with the major parts of the wing.

The particular design of a wing depends on such factors as size, weight, speed, rate of climb, and use of the aircraft. The wing must be constructed so that it holds its all-important aerodynamic shape under the extreme stresses of combat maneuvers or wing loading.

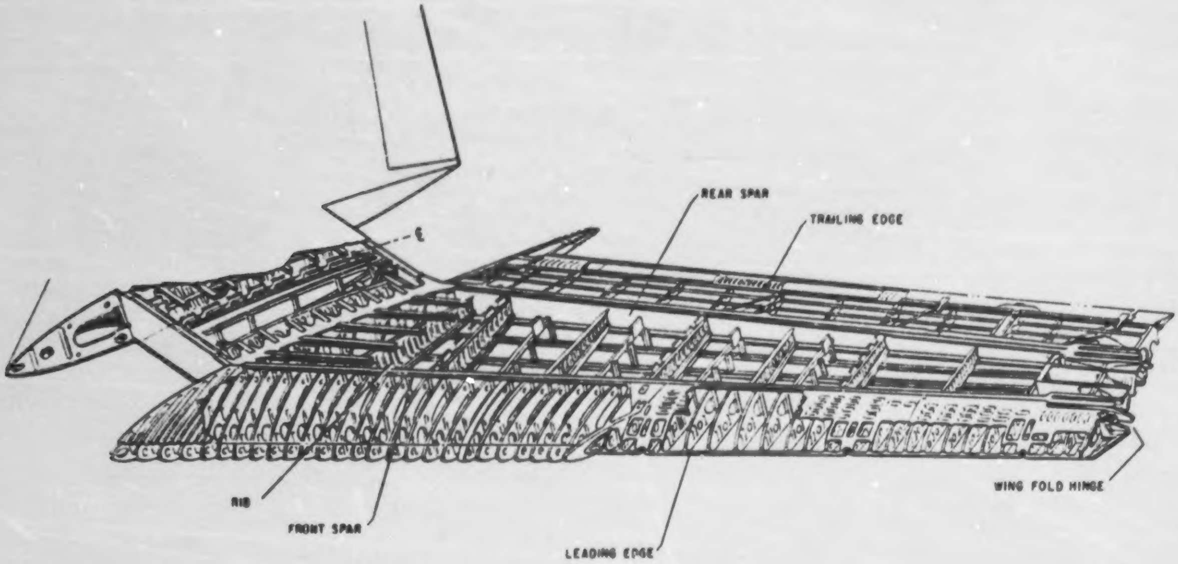
Wing construction is similar in most modern aircraft. In its simplest form, the wing is a framework composed chiefly of spars and ribs covered with metal. The construction of an aircraft wing is shown in figure 4-8.

The spars are the main structural members of the wing, extending from the fuselage to the tip. All the load that is carried by the wing is ultimately taken up by the spars; therefore, they are designed to have great bending strength. Ribs give the wing section its shape and also transmit the airload from the wing covering to the spars. They extend from the leading edge to the trailing edge of the wing.


16
22
27
37
47
CANTED BLKD 81.8
103
111.8
131.9
200
202.5
208.5
214.5
220.5
228.3
238
245.5
252
263
277.5
54.5
61.3
69
77
93
111
119.5
128.5
131
141
152
163.8
170.2
177.2
184.2
190.5
196.5
283
292.5
307.5
322.5
337.5
352
364
373
376
400
418
430

AN.32

Figure 4-7.–Typical fuselage station diagram.



AN.33

Figure 4-8.–Wing construction.

In addition to the main spars, some wings have a false spar to support the ailerons and flaps. Most aircraft wings have a removable tip which streamlines the outer end of the wing.

Most the Navy's new high performance aircraft are designed with a wing referred to as a "wet wing." This term is used to describe the wing which is constructed in such a manner as to allow it to be used for a fuel cell. This type wing is sealed with a fuel resistant compound as it is built and holds fuel without the usual rubber cells or tanks.

The wings of modern naval aircraft are of all-metal, full cantilever construction, and often may be folded for carrier use. The full canti-type means that the wing structure is made very strong and can be fastened to the fuselage without the use of external bracing such as wires or struts.

A complete wing assembly consists of the surface providing lift for the support of the aircraft, together with the necessary flight control surfaces. NOTE: The flight control surfaces on the simple wing may include only ailerons and trailing edge flaps, while the more complex aircraft may have a variety of devices such as leading edge flaps, slats, spoilers, and speed brakes.

Various points on the wing are located by station number. Wing station 0 is located at the centerline of the fuselage, and all wing stations are measured (right or left) from this point in inches.

FLIGHT CONTROL SURFACES

The flight control surfaces are hinged or movable airfoils designed to change the attitude of the aircraft during flight. These surfaces may be divided into three groups, usually referred to as the primary group, secondary group, and auxiliary group.

Primary Group

The primary group includes the ailerons, elevators, and rudder. These surfaces are used for moving the aircraft about its three axes (discussed in chapter 3). The ailerons are attached to the trailing edge of the wings and control the rolling (or banking) motion of the aircraft. The elevators, attached to the horizontal stabilizer, control the climb or descent (pitching motion). The rudder, attached to the vertical stabilizer, determines the horizontal direction of flight.

The ailerons and elevators are generally operated from the cockpit by a control stick on single-engine aircraft and by a wheel and yoke assembly on multiengine aircraft such as transports and patrol aircraft. The rudder is operated by foot pedals on all types of aircraft. (Theory of flight is discussed in detail in chapter 3).

Secondary Group

Included in the secondary group are the trim tabs and spring tabs. Trim tabs are small airfoils recessed into the trailing edges of the primary control surfaces. The purpose of trim tabs is to enable the pilot to trim out any unbalanced condition which may exist during flight, without exerting any pressure on the primary controls. Each trim tab is hinged to its parent primary control surface, but is operated by an independent control.

Spring tabs are similar in appearance to trim tabs, but serve an entirely different purpose. Spring tabs are used to aid the pilot in moving the primary control surfaces.

Auxiliary Group

Included in the auxiliary group of flight control surfaces are the wing flaps, spoilers, speed brakes, and slats.

Wing flaps are used to give the aircraft extra lift and are hinged to either the trailing edge or leading edge of the wing. Wing flaps on most older type aircraft were hinged to the trailing edge of the wing inboard of the ailerons. Some of the later type aircraft have flaps hinged to both the trailing edge and the leading edge of the wings. Their purpose is to reduce the landing speed, thereby shortening the length of the landing run, and to permit landing in small or obstructed areas. In addition, the wing flaps are used during takeoff to shorten the takeoff run.

Spoilers are for the purpose of decreasing wing lift; however, their specific design, function, and use vary with different aircraft. On the P-2 aircraft the spoilers are long narrow surfaces, hinged at their leading edges to the upper surface of the wings. In the retracted position, the spoiler is flush with the wing skin. In the raised position, wing lift is greatly reduced by destroying the smooth flow of air over the wing surface.

Speed brakes are hinged surfaces used for slowing down the speed of an aircraft. Some manufacturers refer to them as dive brakes, others call them dive flaps. On some aircraft the speed brakes are hinged to the lower surface of the fuselage; on others they are attached to the wings. Their primary purpose is to keep the speed of the aircraft from building up too high in dives.

Slats are movable control surfaces attached to the leading edges of the wings. When the slat is closed, it forms the leading edge of the wing. When in the open position (extended forward), a slot is created between the slat and the wing leading edge. At low airspeeds this increases lift and improves handling characteristics, allowing the aircraft to be controlled at airspeeds below the otherwise normal landing speed.

STABILIZING SURFACES

The stabilizing surfaces consist of vertical and horizontal airfoils, called the vertical stabilizer (or fin), and the horizontal stabilizer. These two airfoils, together with the rudder and elevators (when used), form the tail section or empennage of the aircraft.

The primary purpose of the stabilizers is to stabilize the aircraft; that is, to keep the aircraft in straight and level flight. Older type aircraft are constructed with the rudder hinged to the trailing edge of the vertical stabilizer and the elevators hinged to the trailing edge of the horizontal stabilizers. Most new high performance aircraft have movable horizontal stabilizers instead of fixed stabilizers and elevators. One new aircraft (the A-5) has a movable vertical stabilizer. The movable stabilizer is hydraulically controlled from the cockpit.

Construction of the stabilizers is similar to that of the wings. Some of the larger carrier type aircraft have vertical stabilizers which are folded hydraulically to facilitate movement aboard aircraft carriers.

ALIGHTING GEAR

Landing Gear

The landing gear of an aircraft consists of main and auxiliary units. The main landing gear consists of two landing gear units, one under each side of the fuselage or one under each wing. The auxiliary unit is located either under the tail or the nose of the aircraft. Figure 4-9 shows a typical landing gear system.

The landing gear system shown in figure 4-9 consists of three retractable landing gear assemblies. Each main landing gear is equipped with a conventional air-oil shock strut, a wheel brake assembly, and wheel and tire assembly. The nose landing gear is equipped with a conventional air-oil shock strut, a shimmy damper, and a wheel and tire assembly.

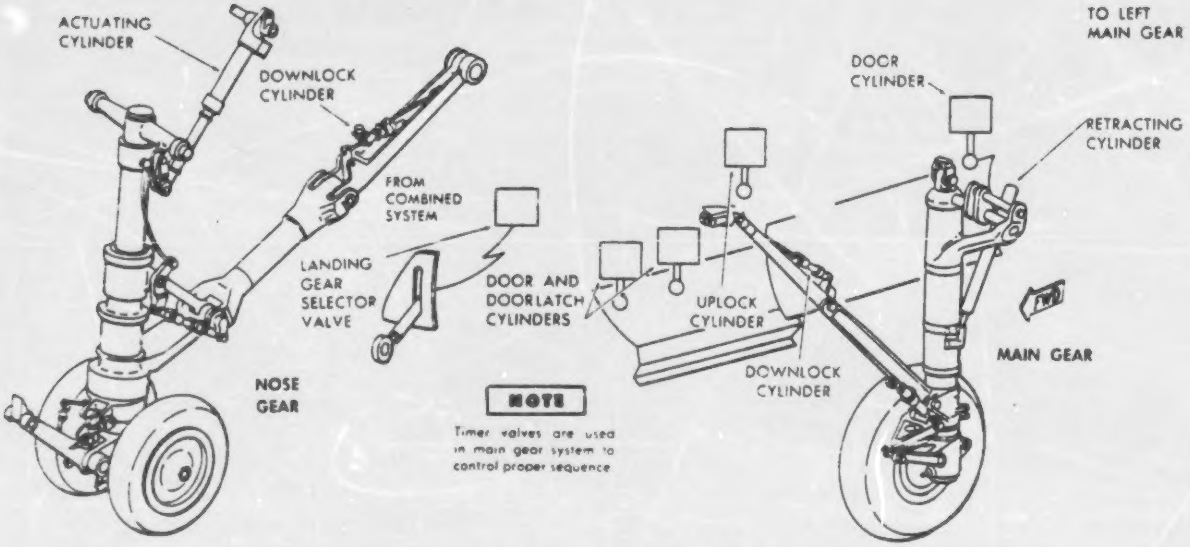
The shock strut is designed to absorb the shock that would otherwise be transmitted to the airframe during landing, taxiiing, and takeoff. The air-oil type strut is used on all naval aircraft. This type strut is composed of two telescoping cylinders filled with hydraulic fluid and compressed air or nitrogen. Figure 4-10 shows the internal construction of one type of air-oil shock strut.

The shimmy damper is a device used to control vibration, or shimmy, through hydraulic dampening. The shimmy damper is either attached to or built integral with the nose gear and prevents shimmy of the nosewheel during taxiing, landing, and takeoff.

The main landing gear is equipped with brakes for stopping the aircraft and assisting the pilot in steering the aircraft on the ground. Brake assemblies may be either the single, dual, or multiple disk, segmented rotor, or expander tube type depending upon the designer of the aircraft and the type of aircraft.

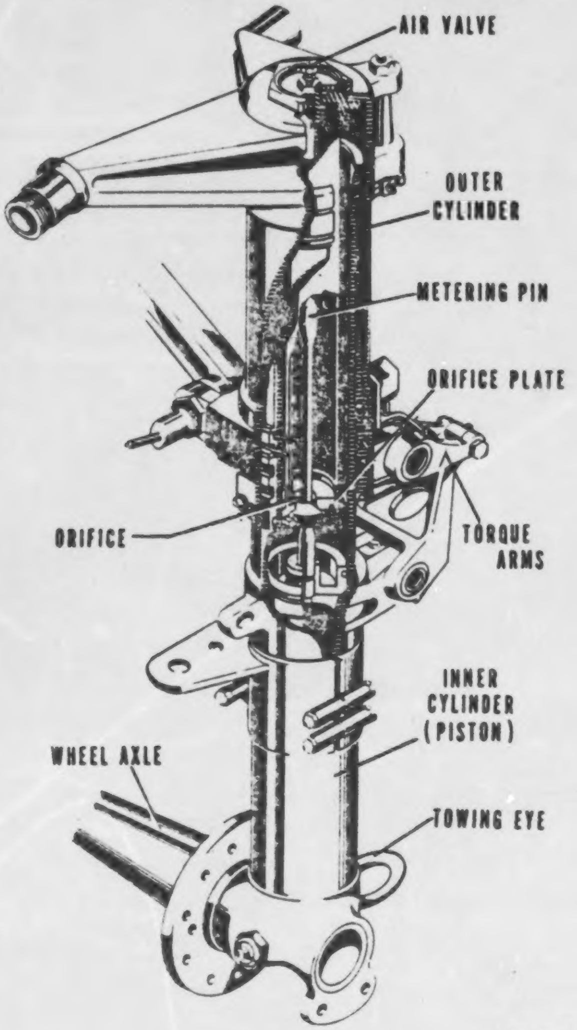
The nose gear of most aircraft can be steered from the cockpit. This provides greater ease and safety on the runway in landing and taking off and on the taxiway in taxiing.

For more information concerning landing gear components (shock struts, shimmy dampers, actuating cylinders, and brakes) refer to Aviation Structural Mechanic H 3 & 2, NavPers 10310-A.


ACTUATING CYLINDER
DOWNLOCK CYLINDER
FROM COMBINED SYSTEM
LANDING GEAR SELECTOR VALVE
DOOR AND DOORLATCH CYLINDERS
NOSE GEAR
NOTE
Timer valves are used in main gear system to control proper sequence
UPLOCK CYLINDER
DOWNLOCK CYLINDER
DOOR CYLINDER
TO LEFT MAIN GEAR
RETRACTING CYLINDER
FWD
MAIN GEAR

AN.34

Figure 4-9.–Typical landing gear system.



AN.35

Figure 4-10.–Shock strut, showing internal construction.

Arresting Gear

Carrier type aircraft are equipped with an arresting hook for stopping the aircraft when it lands on the carrier. The arresting gear is composed of an extendible hook and the mechanical, hydraulic, and pneumatic equipment necessary for hook operation. The arresting hook on most aircraft is mechanically released, pneumatically lowered, and hydraulically raised.

The hook is hinged from the structure under the rear of the aircraft. A snubber which is similar to an automobile shock absorber is used to hold the hook down and prevent it from bouncing when it strikes the carrier deck.

CATAPULT EQUIPMENT

Carrier type aircraft are equipped with facilities for catapulting the aircraft off the aircraft carrier. This equipment consists of one or two hooks (depending on the type of aircraft) mounted on the landing gear, fuselage, or the wings, and a holdback fitting mounted on the rear of the aircraft (fig. 4-11). The hooks are designed to accommodate the cable bridle which is used to hook the aircraft to the ship's catapult. The holdback assembly allows the aircraft to be secured to the carrier deck for full power turnup of the engine prior to takeoff. NOTE: The holdback tension bar (fig. 4-11) separates when the catapult is fired; thus, allowing the aircraft to be launched with the engine at full power.

The nose gear equipment is the Navy's newest method of attaching an aircraft to the catapult for launching. All the latest Navy carrier-based aircraft are equipped for this type launching. A track is attached to the deck to guide the nosewheel into position. (See fig. 4-12.) The track also has provisions for attaching the nose gear to the catapult shuttle and for holdback. The nose gear launch equipment requires fewer men, the hookup is accomplished more safely, and time is saved in positioning an aircraft for launch, in comparison with the bridle and holdback pendant method of catapult hookup for launching.

FLIGHT CONTROL MECHANISMS

The term "flight control mechanisms" refers to the linkage which connects the control(s) in the cockpit with the flight control surface(s). Several types of flight control mechanisms are used in naval aircraft. Some are manually operated; others are power operated.

Manually operated flight control mechanisms may be further divided into three general types–cable operated, push-pull tube operated, and torque tube operated. Some systems may combine two or more of these types.

In the manually operated cable system, cables are connected from the control in the

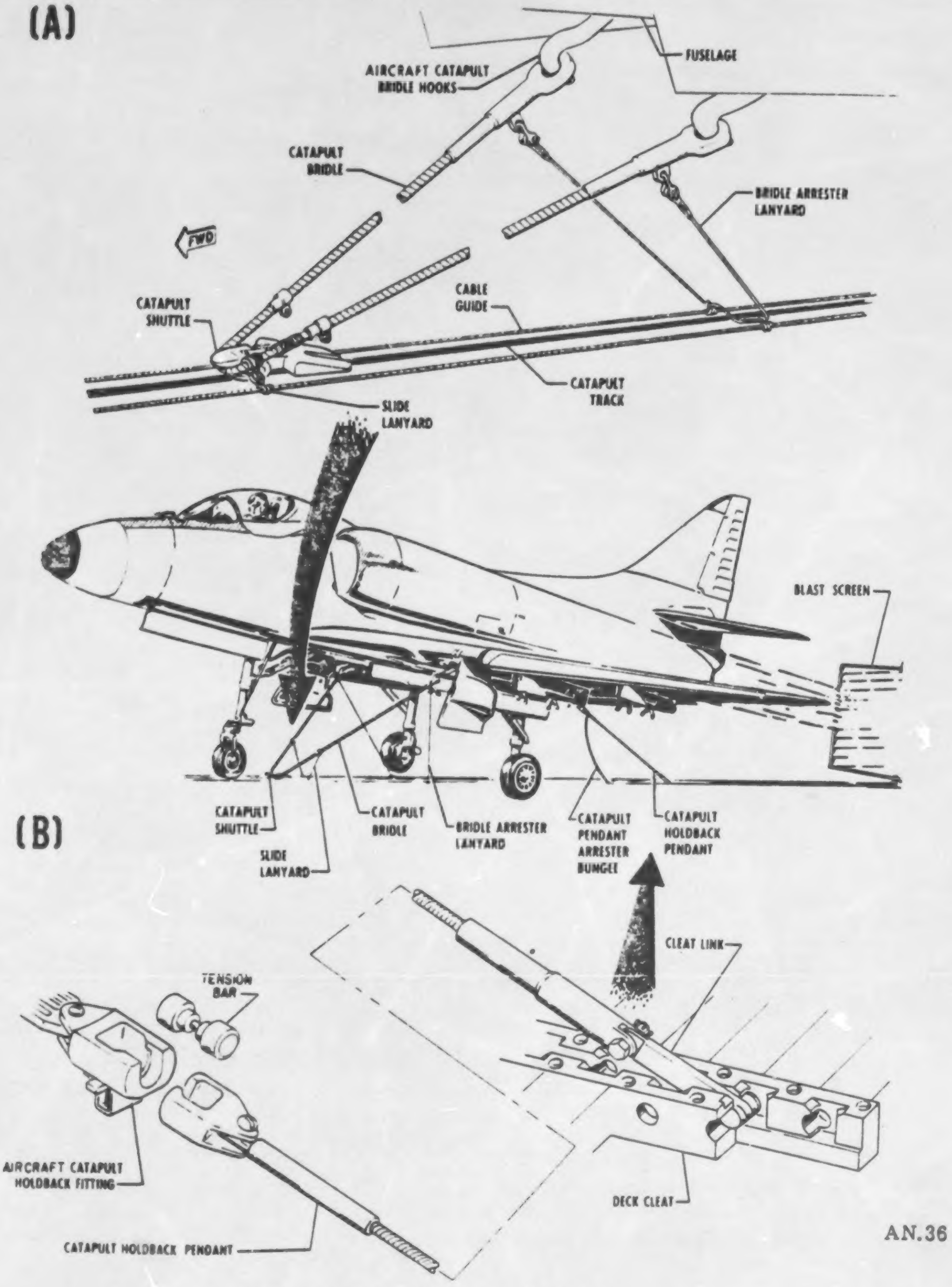
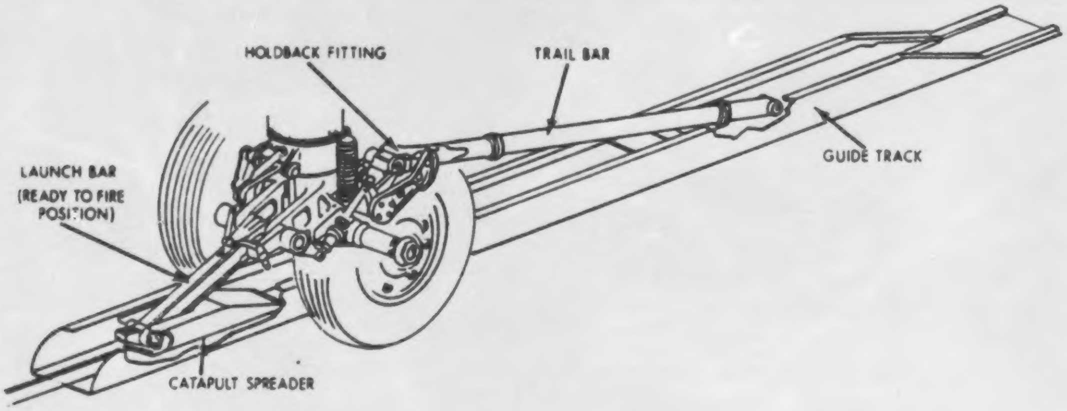

(A)
AIRCRAFT CATAPULT BRIDLE HOOKS
FUSELAGE
CATAPULT BRIDLE
BRIDLE ARRESTER LANYARD
FWD
CABLE GUIDE
CATAPULT SHUTTLE
CATAPULT TRACK
SLIDE LANYARD
BLAST SCREEN
CATAPULT SHUTTLE
CATAPULT BRIDLE
BRIDLE ARRESTER LANYARD
CATAPULT PENDANT ARRESTER BUNGEE
CATAPULT HOLDBACK PENDANT
(B)
SLIDE LANYARD
CLEAT LINK
TENSION BAR
AIRCRAFT CATAPULT HOLDBACK FITTING
DECK CLEAT
CATAPULT HOLDBACK PENDANT
AN.36

Figure 4-11.–Catapult equipment.



AN.37

Figure 4-12.–Nose gear launch equipment.

cockpit to a bellcrank or sector. The bellcrank is in turn connected to the control surface. Movement of the cockpit controls transfers force through the cable to the bellcrank which in turn moves the control surface.

In a push-pull tube system, metal push-pull tubes (or rods) are used as a substitute for the cables. Push-pull tubes get their name from the manner in which they transmit force.

In the torque tube operated system, metal tubes (rods) with gears at the ends of the tubes, are used. Motion is transmitted by rotating the tubes and gears. This type linkage is used only in trim tab systems.

On all high performance aircraft, the control surfaces have such great pressures exerted on them that it is physically impossible for the pilot to move the controls manually. As a result, power-operated control mechanisms are used. In a power-operated system, a hydraulic actuator (cylinder) is incorporated within the linkage to assist the pilot in moving the control surface.

A typical flight control mechanism is shown in figure 4-13. This is the elevator control of a light weight trainer type aircraft. It consists of a combination of push-pull tubes and cables.

The control sticks in the system shown in figure 4-13 are connected to the forward sector by push-pull tubes. The forward sector is connected to the rear (aft) sector by means of cable assemblies. The aft sector is connected to the control (elevator) by another push-pull tube assembly.

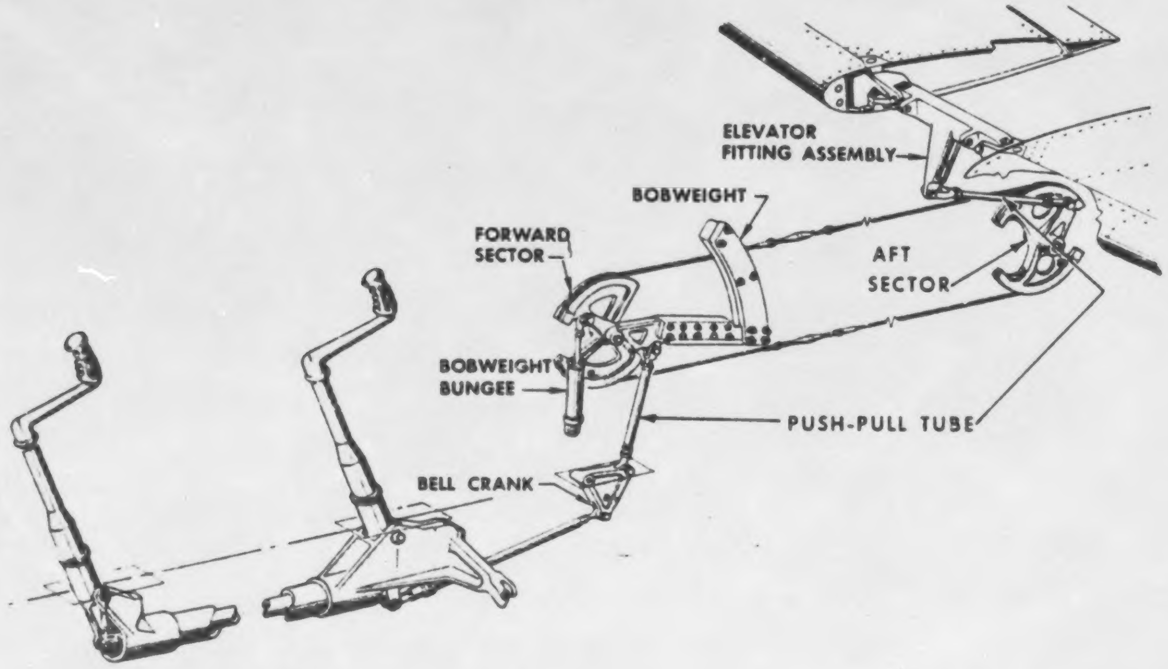
When the pilot moves the control stick to the rear, the push-pull tubes which connect the stick to the forward sector move forward. The forward movement of these push-pull tubes cause the forward sector to move clockwise. The cable linkage between the two sectors causes the aft sector to move clockwise also. The clockwise movement of the aft sector moves the push-pull tube connecting it to the elevator to the rear. The aft movement of this push-pull tube pulls the elevator up, thereby causing the aircraft to go into a noseup attitude.

For more information concerning flight control mechanisms refer to Aviation Structural Mechanic S 3 & 2, NavPers 10308-A.

AIRCRAFT HYDRAULIC SYSTEMS

Most naval aircraft use some form of hydraulic system. The aircraft hydraulic system performs many functions. Among the units commonly operated by hydraulics are landing gear, wing flaps, dive flaps, wing folding mechanisms, flight control surfaces, gun chargers, canopy, bomb bay doors, and wheel brakes.

Hydraulics has many advantages as a power source for operating these various units on aircraft. Hydraulics combines the advantages of light weight, ease of installation, simplification of inspection, and minimum maintenance requirements. Hydraulic operation is also almost 100 percent efficient, with only a negligible loss due to fluid friction.



AN.38

Figure 4-13.–Typical flight control mechanism.

To make the picture complete, some disadvantages of hydraulics are also listed here. An obvious disadvantage of hydraulics is the possibility of leakage. Both internal and external leakage may cause the complete system to become inoperative. Another disadvantage is contamination. Foreign matter in the system can cause malfunction of any unit; for this reason, cleanliness in hydraulics cannot be overemphasized.

COMPONENTS IN A BASIC SYSTEM

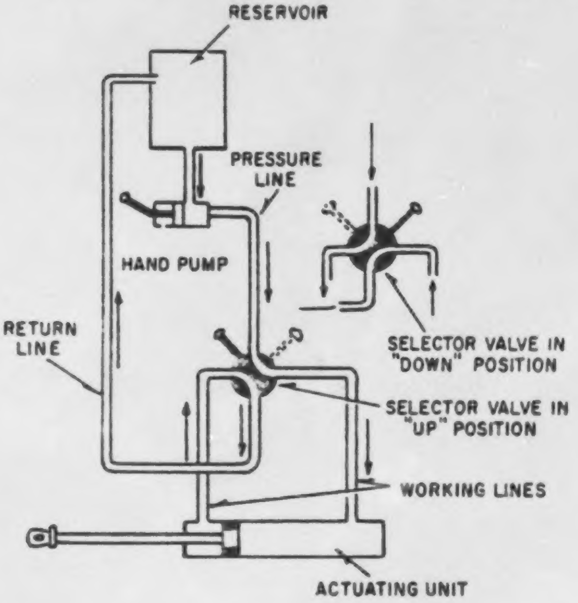
Basically, any hydraulic system must contain the following units:

1. A reservoir to hold a supply of hydraulic fluid.
2. A pump to provide a flow of fluid.
3. Tubing to transmit the fluid.
4. A selector valve to direct the flow of fluid.
5. An actuating unit to convert the fluid pressure into useful work.

A simple system using only these essentials is shown in figure 4-14.

The flow of hydraulic fluid can be traced readily from the reservoir through the pump to the selector valve. With the selector valve in the position shown, the flow of fluid created by the pump flows through the valve to the right-hand end of the actuating cylinder. Fluid pressure then forces the piston to the left and at the same time the fluid which is on the left of the piston is forced out, up through the selector valve, and back to the reservoir through the return line.

When the selector valve is moved to the position indicated by the dotted lines, the fluid from the pump then flows to the left side of the actuating cylinder, thus reversing the process. Movement of the piston can be stopped at any time simply by moving the selector valve to neutral. In this position, all four ports are closed and pressure is trapped in both working lines. This basic system is one from which any hydraulic system can be derived. Additions may be made to it for the purpose of providing additional sources of power, operating additional cylinders, making operation more automatic, or


RESERVOIR
PRESSURE LINE
HAND PUMP
RETURN LINE
SELECTOR VALVE IN "DOWN" POSITION
SELECTOR VALVE IN "UP" POSITION
WORKING LINES
ACTUATING UNIT

AN.39

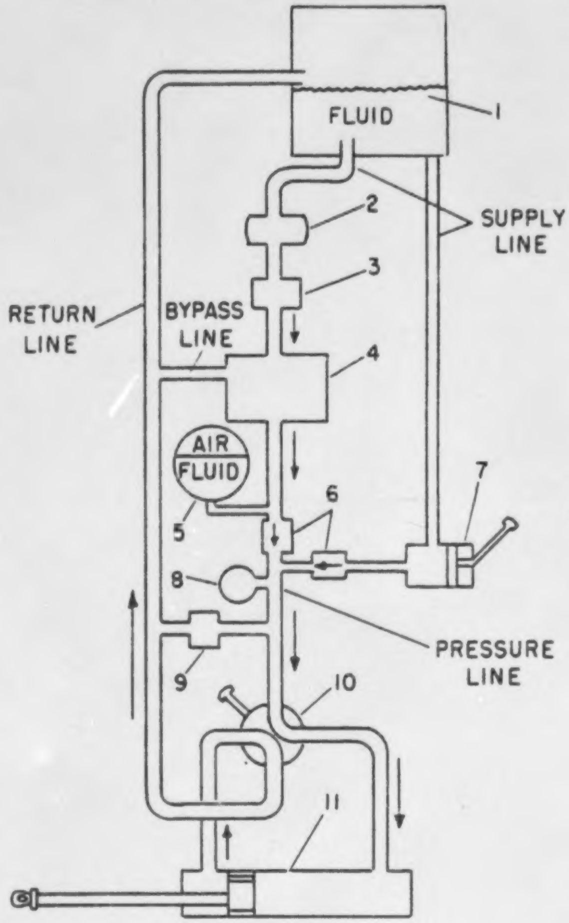
Figure 4-14.–Basic hydraulic system, hand-pump operated.

increasing the reliability; but these additions are all made on the framework of the basic hydraulic system diagramed in figure 4-14.

Figure 4-15 shows a basic system with the addition of a power-driven pump and the following essential components: Filter, pressure regulator, accumulator, pressure gage, relief valve, and two check valves. The function of these components follows. For construction, operating features, and maintenance of these components, refer to Aviation Structural Mechanic H 3 & 2, NavPers 10310-A.

The filter (3, fig. 4-15) removes foreign particles from the fluid, preventing dust, grit, and other undesirable matter from entering the system.

The purpose of the pressure regulator (4) is to unload or relieve the power-driven pump when the desired pressure in the system is reached. It is therefore often referred to as an UNLOADING VALVE. When none of the actuating units are being operated and pressure in the line between the pump and selector valve builds up to the desired point, a valve in the pressure regulator automatically opens and fluid is bypassed back to the reservoir. This bypass line is shown in figure 4-15 leading from the pressure regulator to the return line.


FLUID
1
2
3
SUPPLY LINE
RETURN LINE
BYPASS LINE
4
AIR
FLUID
5
6
7
8
PRESSURE LINE
9
10
11

1. Reservoir.
2. Power pump.
3. Filter.
4. Pressure regulator.
5. Accumulator.
6. Check valves.
7. Hand pump.
8. Pressure gage.
9. Relief valve.
10. Selector valve.
11. Actuating unit.

AN.40

Figure 4-15.—Basic system with addition of power pump.

NOTE: Many aircraft hydraulic systems do not use a pressure regulator. These systems use a pump which automatically adjusts to supply the proper volume of fluid as needed.

The accumulator (5) serves a twofold purpose. It serves as a cushion or shock absorber by maintaining an even pressure in the system, and it stores enough fluid under pressure to provide for emergency operation of certain actuating units. It is designed with a compressed-air chamber separated from the fluid by a flexible diaphragm, synthetic rubber bladder, or a movable piston.

The pressure gage (8) indicates the amount of pressure in the system.

The relief valve (9) is a safety valve installed in the system so that fluid is bypassed through the valve to the return line and back to the reservoir in case excessive pressure is built up in the system.

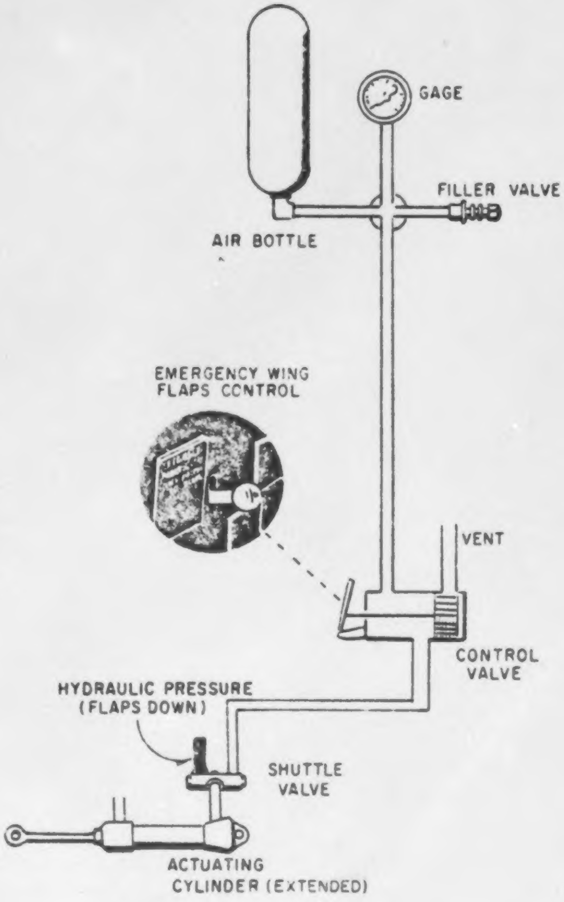
Check valves allow the flow of fluid in one direction only. There are numerous check valves installed at various points in the lines of all aircraft hydraulic systems. A careful study of figure 4-15 will reveal why the two check valves are necessary in this system. One check valve prevents power pump pressure from entering the hand-pump line; the other prevents hand-pump pressure from being directed to the accumulator.

PNEUMATIC SYSTEMS

There are two types of pneumatic systems currently in use in naval aircraft. One type utilizes storage bottles for an air source, and the other has its own air compressor.

The storage bottle type system (fig. 4-16) is generally used only for emergency operation. This type system consists of one or more air storage cylinders, a control in the cockpit for releasing the contents of the cylinders, a ground charge (filling) valve, and connecting lines and fittings. The storage bottles must be filled prior to flight with compressed air or nitrogen. Examples of the air storage cylinder type pneumatic system are emergency brakes, emergency landing gear extension, emergency flap extension, and canopy release mechanisms.

When the emergency system control handle in the cockpit is placed in the down position, the compressed air in the storage bottle is routed through the shuttle valve to the actuating cylinder. (NOTE: The shuttle valve is a pressure-operated valve which separates the normal hydraulic system from the emergency pneumatic system.) When the control handle is returned to the normal position, the air pressure in the lines is vented overboard through the vent port of the control valve.


GAGE
FILLER VALVE
AIR BOTTLE
EMERGENCY WING FLAPS CONTROL
VENT
CONTROL VALVE
HYDRAULIC PRESSURE (FLAPS DOWN)
SHUTTLE VALVE
ACTUATING CYLINDER (EXTENDED)

AN.41

Figure 4-16.–Emergency pneumatic system.

The other type of pneumatic system in current use has its own compressor and other equipment necessary for maintaining an adequate supply of compressed air during flight. Most systems of this type must be serviced on the ground prior to each flight. The air compressor used in most aircraft is driven by a hydraulic motor. Aircraft which have an air compressor use the compressed air for normal system operations such as canopy opening and closing, as well as emergency system operation.

CHAPTER 6

ELECTRICAL SYSTEMS AND INSTRUMENTATION

The discussions of engine theory, found in this training manual, probably have already given you some idea of the importance of electricity and instrumentation in modern naval aircraft.

Primarily, there are two sources of electrical energy in an aircraft—the generator in which mechanical energy is converted into electrical energy and the battery in which chemical energy is converted into electrical energy. Of these two, the generator is the main source and the battery is the auxiliary source of electrical energy.

AIRCRAFT STORAGE BATTERIES

The function of the aircraft storage battery is to provide a reserve source of electrical power for operating the electrical systems of an aircraft. During normal aircraft operation, the generator supplies the primary source of electrical energy, and maintains the battery in a charged state. The battery supplies power to the aircraft only when the speed of the engine or generator drive system becomes so slow that the generator's output voltage falls below the battery voltage.

The battery is the emergency power source for the aircraft. For this reason extreme care must be taken to see that every precaution is made to maintain the battery in perfect condition. Therefore, the battery should never be used for starting engines or servicing equipment if another source of power is available. Such unnecessary usage tends to shorten the life of the battery and keeps the battery in poor condition to meet emergency operation requirements. During the periods when the engines are idling or being started, the electrical load should be kept at a minimum. The service life of the aircraft battery depends a great deal upon the frequency and quality of care it is given. Batteries that are abused or that receive careless treatment and servicing generally have their service life ended prematurely.

LEAD-ACID BATTERY

The most common aircraft batteries in use today are the lead-acid type and the nickel-cadmium type. However, a more recent type known as the silver-zinc batteries are being used in some aircraft.

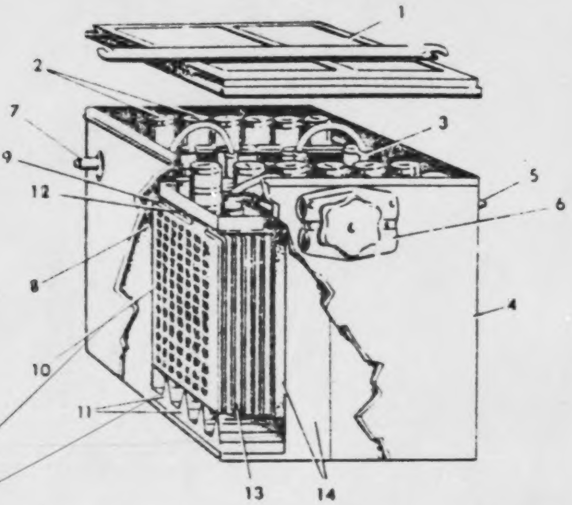
Fundamentally, there is no difference in the operation of the lead-acid aircraft battery and the lead-acid automobile battery. Both types of these batteries have their plates immersed in a solution of sulfuric acid and water and operate on the same basic principles.

The storage battery used in aircraft consists of a number of cells connected in series. In a typical (lead-acid) battery, each of these cells contains positive plates of lead peroxide, negative plates of spongy lead, and a liquid mixture of sulfuric acid and water (electrolyte). When the battery is connected to an electrical circuit through which it can force current to flow, the chemicals in the battery react with each other in such a way as to produce a voltage. In this state, the battery is said to be discharging. When the battery is connected to a source of higher voltage, current is forced through the battery, and the chemical action is reversed. In this state, the battery is being charged. In discharging, the chemical energy stored in the battery is changed to electrical energy; in charging the electrical energy supplied to the battery is changed to chemical energy and stored. It is possible to charge and discharge a storage battery many times before it deteriorates permanently.

Aircraft batteries require a great deal more care than automobile batteries because of the unusual conditions under which they operate. The aircraft battery is usually shielded by enclosing it in a grounded, metal covering housing. (See fig. 6-1.)

Most aircraft batteries are equipped with a quick-disconnect unit as shown in figure 6-1. This unit is a heavy-duty connector with a handle attached to a threaded post. The battery cables can be disconnected from the battery posts simply by turning the handle and pulling the quick-disconnect unit.

Aircraft batteries are built so that they do not leak even when the aircraft is flying upside down. This is made possible through the use of "nonspill" vent plugs (caps) which contain a valve that is operated by a balanced lead weight. The valve is normally open; but when the plug is tilted through a wide angle, or inverted, the weight closes the valve.



1. Metal cover.
2. Fillercap and vent plug.
3. Cell connectors.
4. Metal container.
5. Vent.
6. Quick-disconnect receptacle and plug.
7. Vent.
8. Cell container.
9. Positive plate group strap.
10. Plate.
11. Plate supports.
12. Negative plate group strap.
13. Separators.
14. Cells.

AN.82

Figure 6-1.–Typical aircraft lead-acid storage battery.

Since it is important to keep their weight at a minimum, aircraft batteries have a small capacity. Consequently, they must be used and serviced with great care. For example, if connected to a charging voltage that is too high, an aircraft battery overcharges in a short time. This overcharging may cause premature loosening of the active material on the plates. When a battery is being charged, a portion of the energy is dissipated in the electrolysis of the water in the electrolyte. Thus, hydrogen is released at the negative plates and oxygen at the positive plates. These gases bubble up through the electrolyte and collect in the airspace at the top of the cell. If violent gassing occurs when the battery is first placed on charge, the charging rate is too high. (NOTE: The rate should never be so high that violent gassing occurs.) If the rate is not too high, steady gassing, which develops as the charging proceeds, indicates that the battery is nearing a fully charged condition. A mixture of hydrogen and air can be dangerously explosive. Smoking, electric sparks, or open flames should not be permitted near charging batteries.

NICKEL-CADMIUM BATTERY

Nickel-cadmium batteries have several major advantages over the other commonly used storage batteries. A few of these advantages are as follows:

1. They can be recharged by the constant potential method in an extremely short time, usually less than 1 hour.
2. They maintain a relatively steady voltage even when being discharged at a high rate.
3. If they are overcharged, or charged in the wrong direction, they are not permanently damaged.
4. They can stand idle in any state of charge for an indefinite time.
5. They retain their charge if stored in a charged condition for prolonged time periods.
6. They are not damaged by freezing.
7. They are not subject to failure from vibration or severe jolting.

8. They do not normally exude corrosive fumes.

9. They are composed of individually replaceable cells.

10. No capacity tests are necessary to determine their condition.

The battery is not adversely affected by extremely low temperatures. The lower the temperature the better the battery retains its charge when it is in idle storage or in standby service. The battery does not have to be removed from the aircraft during cold weather under normal operating conditions.

Nickel-cadmium batteries accept a charge at temperatures as low as -65° F. When they are charged at low temperatures, however, a longer period is required to bring the batteries up to full charge. Generally, the lower the temperature the longer the time required for charging.

The voltage on discharge is lower at low temperatures than at normal temperatures. Voltage decreases with a decrease in temperature or with an increase in discharge rate. The capacity is similarly affected. However, the battery does not need to be operated intermittently at low temperatures as many other batteries do.

The lead-acid battery contains sulfuric acid solution (H_2SO_4) for the electrolyte, while the nickel-cadmium battery utilizes potassium hydroxide (KOH). Unlike the lead-acid type, the nickel-cadmium battery does not require any venting provisions under normal conditions. Nickel and cadmium are used as the electrodes. The active material on the negative plate is cadmium oxide. When charging current is applied, this material gradually loses its oxygen and becomes metallic cadmium. The active material of the positive plate is nickel oxide. This is brought to a higher state of oxidation by the charging current. As long as charging continues, these changes take place until both materials are completely converted. The electrolyte in a nickel-cadmium battery does not enter into any chemical reaction with either the positive or negative plates. It acts only as a conductor of current between them and there is no significant change in specific gravity regardless of the state of charge. Because the electrolyte is a conductor only, there is no flaking or shedding of active materials from the plates as in lead-acid batteries. No external vent system is required since gassing of this type battery is practically negligible.

As a safety precaution, relief valves have been installed in the fill hole caps of each cell in order to release any excess gas that is formed when the battery is charged improperly.

SILVER-ZINC BATTERY

Silver-zinc batteries are easy to maintain and have several inherent advantages over lead-acid batteries. They are lighter, more compact, and can be discharged at higher rates. They have an almost flat voltage discharge curve; are shock proof, vibration proof, and spill proof (no sump jars are required); and do not expel gas at any time.

Unlike other types of batteries, silver-zinc batteries are very sensitive to excessive voltage during charging. Charging voltage should never exceed 2.05 volts per cell. The strong alkaline electrolyte which is used requires special safety precautions.

Silver-zinc batteries are rechargable alkaline units that differ considerably from lead-acid batteries and, to a certain extent, from other alkaline batteries such as the nickel-cadmium. Silver oxide (the positive electrode) and zinc (the negative electrode) are employed as the active elements, while the electrolyte is a strong solution of potassium hydroxide (KOH). When current flows, oxygen from the silver oxide plate moves from the positive plates to the negative plates where it combines with the zinc to form zinc oxide, leaving metallic silver on the positive electrodes.

During the charging periods this process is reversed. The electrolyte acts as a "carrier" and takes no part in the chemical reaction. The state of charge of a silver-zinc battery, therefore, cannot be determined by the specific gravity of the electrolyte, as in the case of a lead-acid battery. The condition of the silver-zinc battery is measured with sufficient accuracy for practical operations by voltmeter readings of the open-circuit voltage.

Silver-zinc batteries, like most others, consist of a number of individual cell units. Fourteen cell units are connected in series to make up a battery having a maximum operating voltage of 25.5 volts and a mean operating voltage of 21.0 volts. The individual cells have plastic cases which are highly resistant to alkalies and are shock proof.

BATTERY SAFETY PRECAUTIONS

The principal hazard in connection with lead-acid batteries is the danger of acid burns when refilling or when handling them. These burns can be prevented by the proper use of eyeshields, rubber gloves, rubber aprons, and rubber boots with nonslip soles. Rubber boots and apron need be worn only when batteries are being refilled. It is a good practice, however, to wear the eyeshield whenever working around batteries to prevent the possibility of acid burns of the eyes. Wood slat floorboards, if kept in good condition, are helpful in preventing slips and falls as well as electric shock from the high-voltage side of charging equipment.

Another hazard is the danger of explosion due to the ignition of hydrogen gas given off during battery charging operation. This is especially true where the accelerated charging method is used. Open flames or smoking should not be permitted in the battery charging room, and the charging rate should be held at a point that prevents the rapid liberation of hydrogen gas. Manufacturers' recommendations as to the charging rates for various size batteries should be closely followed and a shop exhaust system should be used.

Particular care should be taken to prevent short circuits while batteries are being charged, tested, or handled. Hydrogen gas, which is accumulated while charging, is highly explosive and a spark from a shorted circuit could easily ignite the gas, causing serious damage to personnel and equipment.

Extreme caution should be exercised when installing and removing an aircraft battery. The nature of battery construction is such that the batteries are heavy for their size and are somewhat awkward to handle. These characteristics dictate the importance of using proper safety precautions. The information that has just been given, pointing out the danger of battery acid and gassing due to charging, holds true for aircraft maintenance. There is the possibility of acid causing damage to equipment or injury to personnel and the danger of an explosion that may be caused from the gas that is produced as the aircraft generator charges the battery. Follow the prescribed safety precautions in working with batteries.

The electrolyte used in nickel-cadmium and silver-zinc batteries is potassium hydroxide (KOH). This is a highly corrosive alkaline solution, and should be handled with the same degree of caution as sulfuric acid. If KOH is sprayed on any material, wash it immediately with liberal quantities of water and neutralize the affected area with vinegar or a weak solution of acetic acid.

Caution: if KOH touches the skin, wash the affected area thoroughly with liberal quantities of fresh water and neutralize with vinegar, lemon juice, or a weak (5 percent) solution of acetic acid. If the face or eyes are affected, treat as above and report immediately for medical examination and treatment.

A-C AND D-C SYSTEMS

As stated earlier in this discussion, energy for the operation of most electrically operated equipment in an aircraft depends primarily upon electrical energy supplied by a generator. A generator is a machine that converts mechanical energy into electrical energy by electromagnetic induction. A generator which produces alternating-current energy is called an a-c generator or alternator. One which produces direct-current energy is called a d-c generator. Either type, however, operates by the induction of an a-c voltage in coils as a result of varying the amount and direction of the magnetic flux passing through the coils. The major difference between an a-c generator and a d-c generator is in the method by which the electrical energy is collected and applied to the external circuit.

In aircraft using direct-current electrical systems, the d-c generator is the regular source of electrical energy. One or more d-c generators driven by the engine in the aircraft supply electrical energy for the operation of all units in the electrical system and energy for charging the battery. The number of generators is determined by the power requirement of a particular aircraft. In most aircraft, there is only one generator driven by each engine. In some large aircraft, there are two generators on a single engine.

Modern naval aircraft use a-c electrical systems as the primary source of power. Most of the equipment aboard is designed for a.c., and the few requirements that remain for d.c. are normally supplied by a system of rectifiers which change a.c. to d.c. On these type aircraft, the aircraft storage battery has been eliminated. Ground service power is furnished by APU's when the aircraft is being serviced. (Detailed information on the construction and operation of both a-c and d-c generators and motors is contained in Basic Electricity, NavPers 10086-A. Also discussed in the same training manual are the principles of rectification and voltage regulation.)

POWER DISTRIBUTION

Most aircraft have the same type of power distribution system. Power is supplied by the battery and generator. This power is distributed through the various circuits by means of the aircraft frame, connecting wires, units to be operated, bus bars, and feeder lines. To permit cutting off all the current in one quick operation, both the battery and generator feeders are usually provided with master, or main-line switches, which may be controlled remotely by means of relays.

The main bus is a copper bar enclosed within a junction box. To the screw terminals of this bus, fuses are normally attached, and from these fuses wires run to control switches in the cockpit and then to various electrical units located throughout the aircraft. In some installations, other buses, fed from the main bus, are located in compartments occupied by the radio operator and other crew members. Each of these auxiliary buses serves to distribute electrical energy to a special group of devices, eliminating the need for a large number of individual wires from the main bus.

In any electrical circuit, a conducting path must be provided from the source to the unit and then from the unit back to the source. Approximately one-half of the electrical path for most circuits is provided by wires. The other half is provided by the aircraft frame. A typical d-c power distribution system is depicted in figure 6-2.

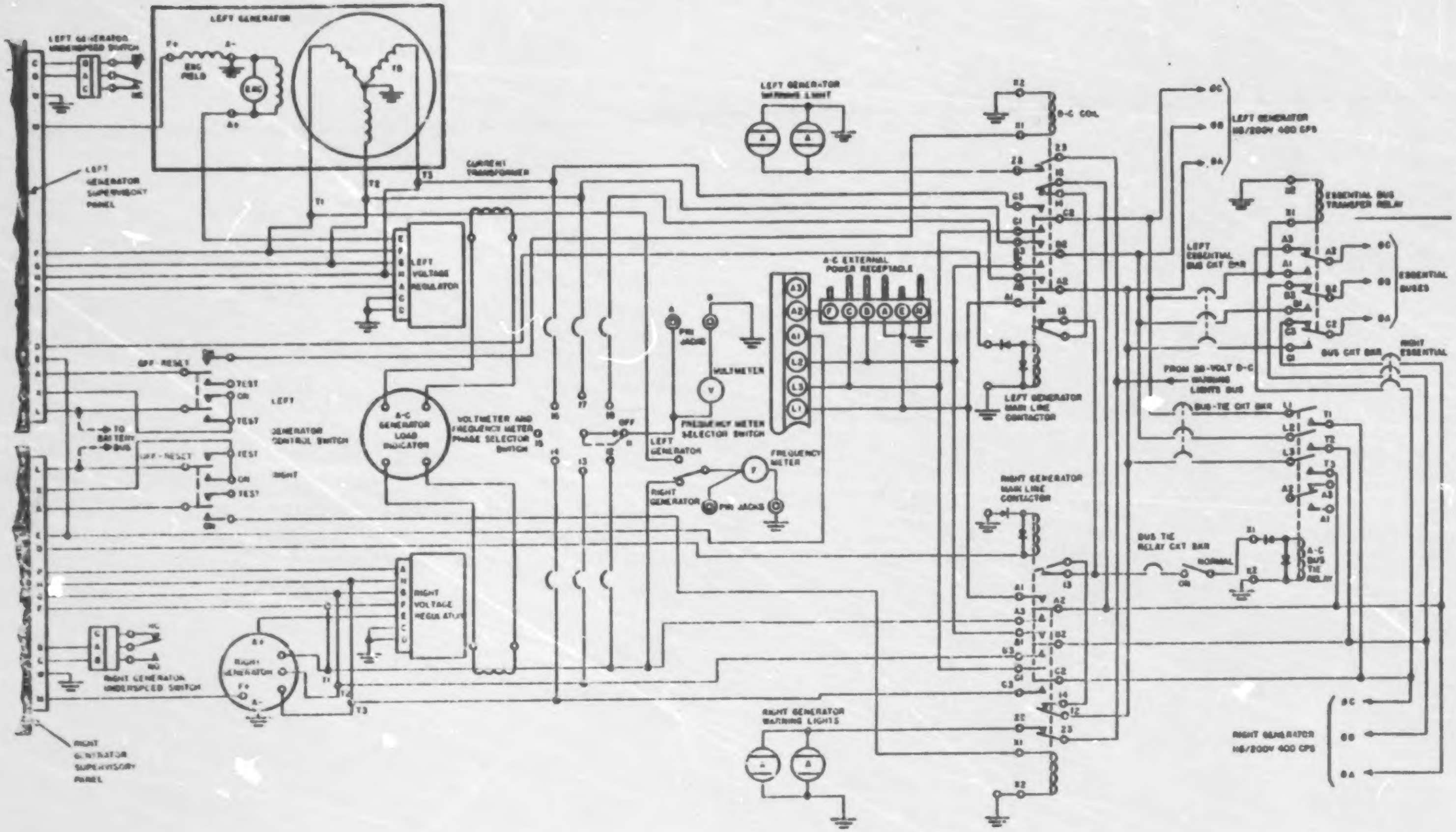
AIRCRAFT INSTRUMENTS

As long as man remains on the ground, his senses give him cues which help him to maintain balance and determine direction and motion. Of all his sensations, vision is the dominant one and the most reliable. Some sensations are just as reliable when a pilot flies through the air as when he moves on the ground; others become most unreliable when the pilot is subjected to the movements and forces of flight. Whenever the pilot can see familiar horizontal or vertical references, he is not confused by his other sensations, even though they may appear to contradict what he sees. The sensations of vision dominate all others.

Sometimes, however, darkness or clouds obscure normal references. Then the pilot may become uncertain as to exactly what his aircraft is doing because he is confused by his false interpretations of some sensations. This condition is called vertigo. This is when the flight instruments come to the rescue and provide the visual references necessary to overcome the pilot's false impressions. Vertigo does not worry the pilot who has trained himself to maintain a knowledge of his position by vision through instruments.

The key to instrument flight is not the pilot's ability to see the instruments but to interpret the picture they portray. To see correctly through the instruments, to anticipate events, to interpret a situation, and to take effective control action are abilities which the pilot must acquire.

There are two ways of grouping aircraft instruments. One is according to the job they do. According to this classification, they fall into three classes–flight instruments, engine instruments, and navigation instruments. The other method of grouping aircraft instruments is according to the principles on which they work. Some operate in relation to changes in temperature or pressure and some by fluid pressure. Others are activated by magnetism and electricity, and still others are gyroscopes.


LEFT GENERATOR
LEFT GENERATOR UNDERSPEED SWITCH
ENG FIELD
T1
T2
T3
LEFT GENERATOR SUPERVISORY PANEL
CURRENT TRANSFORMER
LEFT VOLTAGE REGULATOR
OFF-RESET
TEST
ON
TEST
LEFT
TO BATTERY BUS
GENERATOR CONTROL SWITCH
RIGHT
A-C GENERATOR LOAD INDICATOR
VOLTMETER AND FREQUENCY METER PHASE SELECTOR SWITCH
OFF
LEFT GENERATOR WARNING LIGHT
PRI JACKS
VOLTMETER
FREQUENCY METER SELECTOR SWITCH
LEFT GENERATOR
RIGHT GENERATOR
PRI JACKS
FREQUENCY METER
A-C EXTERNAL POWER RECEPTACLE
A3
A2
A1
L2
L3
L1
D-C COIL
LEFT GENERATOR 115/200V 400 CPS
ØC
ØB
ØA
ESSENTIAL BUS TRANSFER RELAY
LEFT ESSENTIAL BUS CKT BKR
ESSENTIAL BUSES
RIGHT ESSENTIAL BUS CKT BKR
FROM 28-VOLT D-C WARNING LIGHTS BUS
BUS-TIE CKT BKR
LEFT GENERATOR MAIN LINE CONTACTOR
RIGHT GENERATOR MAIN LINE CONTACTOR
BUS TIE RELAY CKT BKR
NORMAL
A-C BUS TIE RELAY
RIGHT VOLTAGE REGULATOR
RIGHT GENERATOR
RIGHT GENERATOR UNDERSPEED SWITCH
RIGHT GENERATOR SUPERVISORY PANEL
RIGHT GENERATOR WARNING LIGHTS
RIGHT GENERATOR 115/200V 400 CPS

AN.83

Figure 6-2.—Typical a-c/d-c power distribution system (a-c section).

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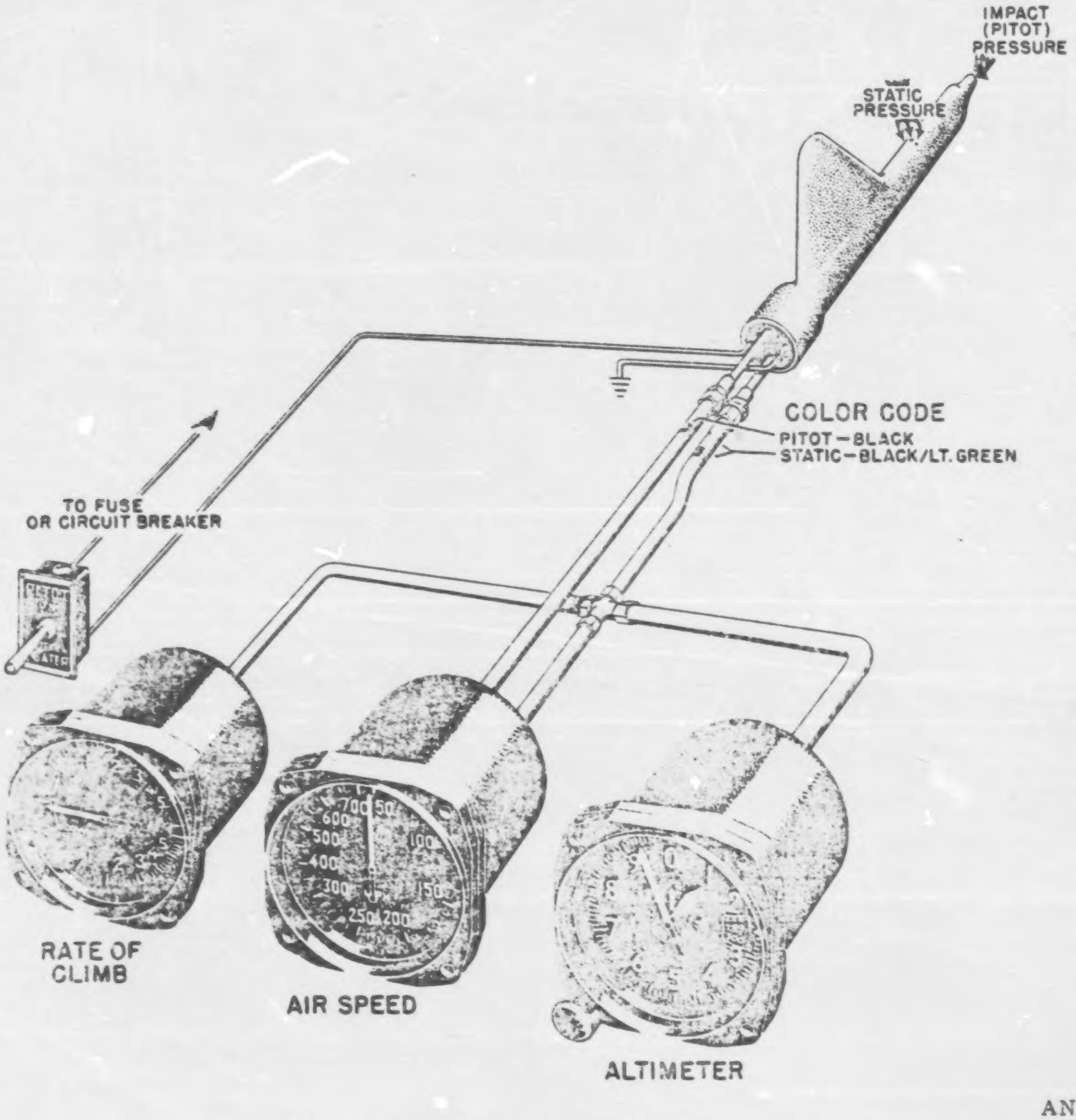
566

PRESSURE ACTIVATED INSTRUMENTS

Atmospheric pressure gradually decrease as one goes higher into the atmosphere. Since this atmospheric pressure is rather constant at any altitude, the altimeter, the airspeed indicator, and the rate of climb indicator are pressure activated instruments.

These instruments operate from the pitot-static system (fig. 6-3). The pitot-static system consists of the pitot system and static system,


IMPACT (PITOT) PRESSURE
STATIC PRESSURE
COLOR CODE
PITOT—BLACK
STATIC—BLACK/LT. GREEN
TO FUSE OR CIRCUIT BREAKER
700
50
600
500
400
300
250
200
150
100
RATE OF CLIMB
AIR SPEED
ALTIMETER

AN.84

Figure 6-3.–Pressure measuring instruments.

which function separately or together, as required, to supply air pressure necessary to the proper operation of various flight instruments.

The pitot system supplies dynamic air pressure to the airspeed indicator and air position indicator controller. The value of this impact air pressure is dependent on the speed of the aircraft through the air–the pressure increases as the speed increases.

The static air pressure in the static system is dependent on the atmospheric pressure of the air surrounding the aircraft. The layer of air directly against the hull skin, even when the aircraft is in motion, is always at atmospheric pressure. This pressure varies only with change in altitude which causes atmospheric pressure variations.

Altimeter

The altimeter is used on aircraft to indicate the height of the aircraft above some fixed point on the ground, or it can measure the aircraft's altitude with respect to sea level (fig. 6-4).

Air from the static side of the pitot-static system surrounds a diaphragm (aneroid) that has been evacuated and sealed. Since all of the air is removed from the inside of the diaphragm, its position at all times represents a balance between the surrounding air pressure, tending to compress the device, and the spring of the metal in the diaphragm tending to expand the device. When the outside air pressure increases, the diaphragm contracts. When the outside air pressure decreases, the diaphragm expands.

When an aircraft climbs to a higher altitude, the atmospheric pressure decreases, so the diaphragm expands, rotating the rocking shaft, swinging the "sector," and rotating the pinion and pointer. The face of the instrument is calibrated so that the pointer indicates the correct altitude of the aircraft in the standard atmosphere.

Modern altimeters have several diaphragms for greater accuracy, and are provided with an adjustment to correct for barometric pressure.

Airspeed and Mach Number Indicator

The airspeed indicator is used to indicate the speed of the aircraft in relation to the air in which it is flying (fig. 6-5). It is operated by

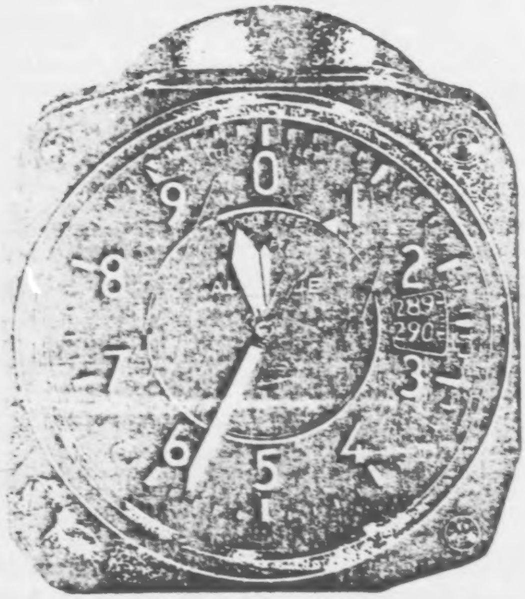


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Figure 6-4.–The altimeter.

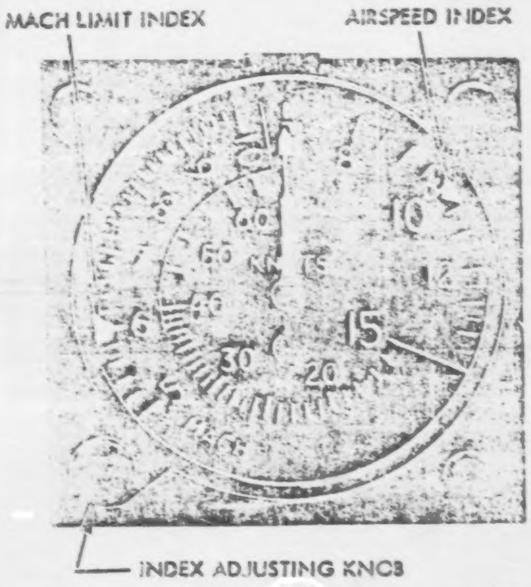

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Figure 6-5.–Airspeed and Mach number indicator.

both pitot (dynamic) and static pressure. As the aircraft moves forward through the air, the pressure supplied from the pitot tube enters the diaphragm and expands or contracts it in proportion to the increase or decrease in the speed of the aircraft. Air at undisturbed atmospheric pressure is supplied from the static tube into the case itself and allows the diaphragm to expand or contract in relation to the atmospheric pressure encountered at the altitude at which the aircraft is flying. As the diaphragm expands, the mechanical linkage turns the pointer around the dial. When the pressure decreases, the diaphragm contracts, and the moving parts, aided by the hairspring, return toward the zero position.

In some instances the speed of an aircraft is expressed in terms of Mach numbers rather than in miles per hour or in knots. The Mach number of any moving body is the ratio of its speed to the speed of sound in the surrounding medium (local speed). For example, if an aircraft is flying at a speed equal to one-half the local speed of sound, it is said to be flying at Mach 0.5. If it moves at twice the local speed of sound, its speed is then Mach 2.

Rate of Climb Indicator

The rate of climb indicator (fig. 6-6) shows the rate at which an aircraft is climbing or descending. The case of a climb indicator is airtight except for a small connection through a restricted passage to the static line. Changes in atmospheric pressure move the operating mechanism that indicates the rate of change. This change occurs only when the aircraft is ascending or descending. When the aircraft ceases to climb or dive, the airflow through the metering units equalizes the pressure and the pointer returns to zero.

Fluid Pressure Gages

A variety of aircraft instruments are operated by fluid pressure. In fluids, the pressure is the same in all directions at any point. When a fluid is confined in a leakproof container an increase in pressure on any part of the confined fluid causes the same increase in pressure throughout the fluid.

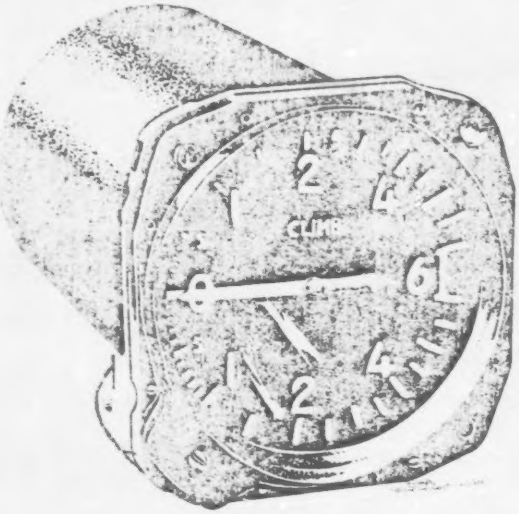

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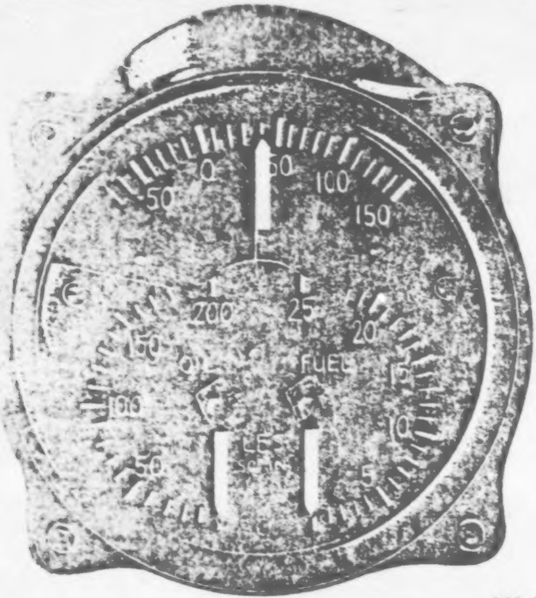
Figure 6-6.–Rate of climb indicator.

Pressure gages are connected into the particular systems for which they are designed by means of small pipelines. Each gage actually becomes a part of the "fluid container" of its system, and is supplied with a small quantity of fluid at the uniform system pressure. They are used to indicate the pressure at which engine oil is forced through the bearings, oil passages, and moving parts of the engine and the pressure at which fuel is being delivered to the carburetor. They are also used to measure the pressure of air in deicer systems and gyroscope drives, of fuel mixture in the intake manifold, and of liquids or gases in a number of other systems.

Engine Gage Unit

The engine gage unit is what the name implies–three separate instruments housed in a single case (oil pressure gage, fuel pressure gage, and oil temperature gage). An engine gage unit is shown in figure 6-7.



AN.88

Figure 6-7.–Engine gage unit

Oil Pressure Indicator

Oil pressure instruments indicate the pressure under which oil is circulating. Oil pressure drops (below normal conditions) warn of impending engine failure caused by lack of oil, oil pump failure, or broken lines. The indicator, shown as the left instrument of the engine gage unit (fig. 6-7), has a range of from 0 to 200 pounds per square inch (psi) and its scale is marked in graduations of 10 psi.

Fuel Pressure Indicator

The fuel pressure indicator, shown as the right instrument of the engine gage unit (fig. 6-7), provides a check on the operation of the fuel pump and the fuel pressure relief valve. It indicates if fuel is being supplied to the carburetor steadily under the correct operating pressure.

Deicing Pressure Indicator

On some aircraft, rubber expansion cells deice the leading edges of wings and stabilizers by expanding and breaking up the ice so that it can be blown away. These are operated by a compressed air system. The deicing pressure indicator (fig. 6-8) measures the difference between the prevailing atmospheric pressure and the pressure inside the system, indicating if there is sufficient pressure to operate the expansion cells.

Manifold Pressure Indicator

In aircraft having reciprocating engines, the manifold pressure indicator measures the pressure at which the fuel mixture is delivered through the intake manifold to the engine. It is essentially an aneroid barometer registering the pressure in inches of mercury. The instrument gives an indication of the power output of the engine, since power output is a direct function of the manifold pressure and the rpm.

In military aircraft with constant speed propeller installations, the manifold pressure gage is the reference for adjusting the power output of the engine. In normal operation, the higher the pressure reading, the higher the power output, and vice versa. Special markings on the faceplate of the instrument indicate the normal range of cruising power output for each particular engine installation. Figure 6-9 shows a typical manifold pressure gage.

TEMPERATURE INDICATORS

Various temperature indications must be known in order for an aircraft to be operated

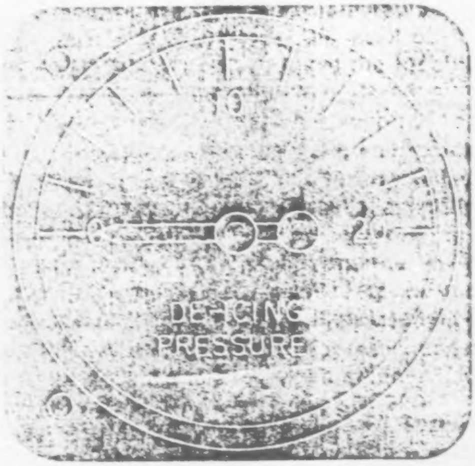


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Figure 6-8.–Deicing pressure indicator.

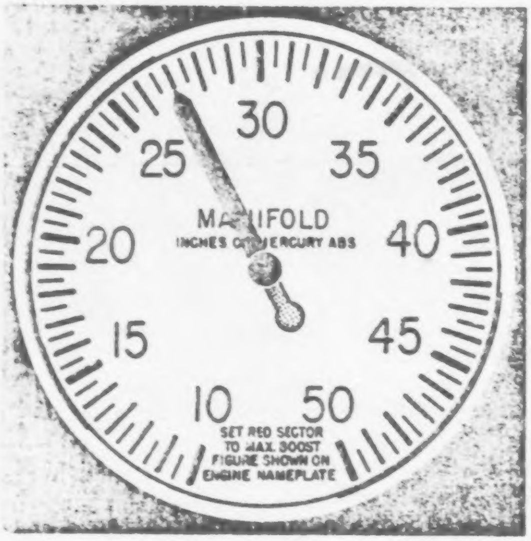

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Figure 6-9.–Manifold pressure indicator.

properly. It is important that the temperature of the engine oil, carburetor mixture, carburetor air, free air, engine cylinders, heater ducts, and exhaust systems of jet engines be known; many other temperatures must be known also, but these are some of the more important ones. Different types of thermometers are used to collect and present this information.

Oil Temperature Indicator

Two types of oil temperature indicators are available for use. One unit consists of an electrical resistance type oil thermometer, supplied electrical current by the aircraft d-c power system. The other unit, the capillary oil thermometer, is a vapor pressure type thermometer which indicates on a dial the temperature of the oil. (See the top instrument of the engine gage unit, fig. 6-7.)

Cylinder Head Temperature Indicator

Thermocouple temperature indicators are used to indicate the temperature of reciprocating engine cylinders, the air temperatures in the heater duct of anti-icing systems, and the exhaust system of jet engines.

A thermocouple is a junction or connection of two unlike metals; such a circuit has two junctions. If one of the junctions is heated to a higher temperature than the other, an electromotive force is produced in the circuit. By including a galvanometer in the circuit, this electromotive force can be measured. The hotter the high-temperature junction (hot junction) becomes the greater the electromotive force produced. By calibrating the galvanometer dial in degrees of temperature, it becomes a thermometer.

The thermocouple thermometer systems used in naval aircraft consists of a galvanometer type indicator, a thermocouple or thermocouples, and thermocouple leads. Some thermocouples are made up of a strip of copper and a strip of constantan that are pressed tightly together. Constantan is an alloy of copper and nickel. Other thermocouples are made up of a strip of iron and a strip of constantan or a strip of chromel and a strip of alumel. Iron-constantan is used mostly in radial engine aircraft; chromel-alumel is used with jet aircraft. Figure 6-10 shows the dial of a cylinder head temperature indicator.

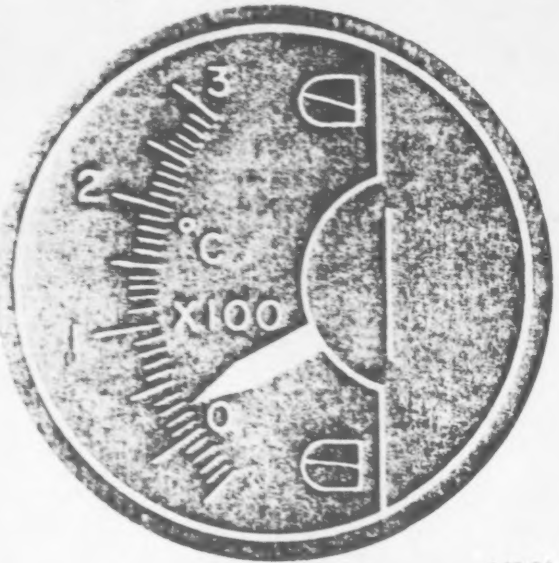
Exhaust Gas Temperature Indicator

The exhaust gas temperature indicator provides a visual indication to the pilot of the engine exhaust gases as they leave the turbine unit.

The thermocouples for the system are located on the turbine frame, a combination indicator and transistorized amplifier located on the instrument panel, and the interconnecting chromel and alumel leads. Power for the indicator-amplifier is supplied from the 115V a-c bus. A typical exhaust gas temperature indicating system for a modern naval jet aircraft is shown in figure 6-11.

ELECTRICALLY ACTIVATED INSTRUMENTS

Electrically activated instruments are usually in the form of small voltmeters which have calibrated dials. These dials can be cali-



AN.91

Figure 6-10.–Cylinder head temperature indicator.

brated to read a variety of conditions, such as airspeed, oil pressure, and engine temperature. Most of the newer types of electrically activated instruments are of the remote indicating type.

The remote indicating instrument has a small alternator, generator, or "activator," which produces an electrical current or voltage. This current is fed through connecting wires into a remote indicator on the instrument panel. The indicator's pointer registers in whatever scale is necessary for that particular instrument. Thus, the "activator" can be located at a considerable distance from the cockpit.

Tachometer

The tachometer is an instrument for indicating the speed of the engine crankshaft. A small alternator or generator is attached to the engine's crankshaft which produces a voltage proportional to its speed. This voltage is fed into the voltmeter (tachometer dial in cockpit), and the pointer registers the revolutions per minute (rpm) on the calibrated dial face. (See fig. 6-12 (A).)

In the case of the gas turbine engine, the tachometer indicates the speed of the main rotor assembly. The tachometer dial is scaled to show the percentage of rpm's being used based on the takeoff rpm (100%), as illustrated in figure 6-12 (B).

It has become necessary to combine several instruments in one because of the complexity of modern aircraft. The dual tachometer has been developed for use in turbojet and multiengine aircraft.

Synchroscope

The synchroscope is an instrument used to indicate whether or not a pair of engines are turning at the same number of rpm's. The instrument consists of a small electric motor, which receives electrical energy from the tachometer generators of both engines that are to be synchronized. If both engines–and thus both generators–are running at exactly the same speed, the synchroscope motor does not turn. The double-ended pointer on the dial of the instrument indicates which engine is turning more rapidly than the other, as shown in figure 6-13.

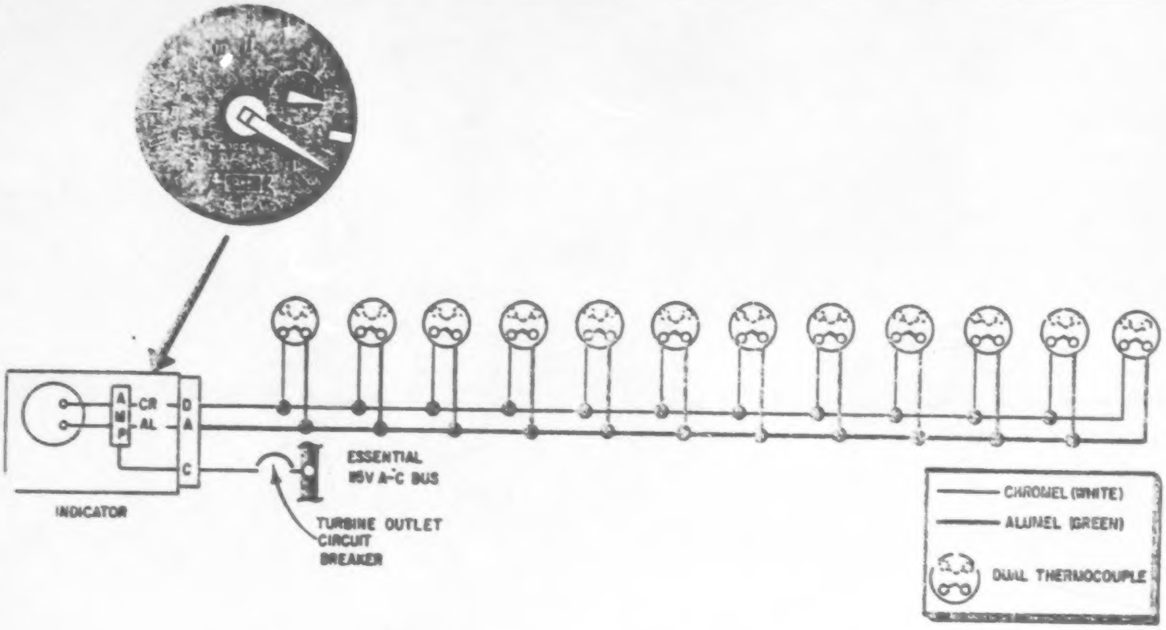
A synchroscope has also been placed in the same case with a dual tachometer. One of these is the helicopter tachometer with synchroscope (fig. 6-14). This instrument is used to show the speed of rotation of the engine crankshaft, the speed of rotation of the rotor shaft, and the slippage of the rotor due to malfunctioning of the clutch or excessive speed of the rotor when the clutch is disengaged in flight.

Fuel Quantity Indicator

The fuel quantity indicator (fig. 6-15) is a capacitor type gage system. It is an electronic fuel measuring device that indicates fuel quantity in pounds. The pointer indicates pounds of fuel on a calibrated dial graduated from 0 to 6 (X 1,000) with line increments every 100 pounds. The fuel quantity remaining in each separate tank or group of tanks is indicated by the pointer when the subject tank or tanks are selected by the pilot with the fuel gage selector switch.

Vertical Scale Indicators

On some modern naval aircraft, a new concept of instrumentation is employed. In

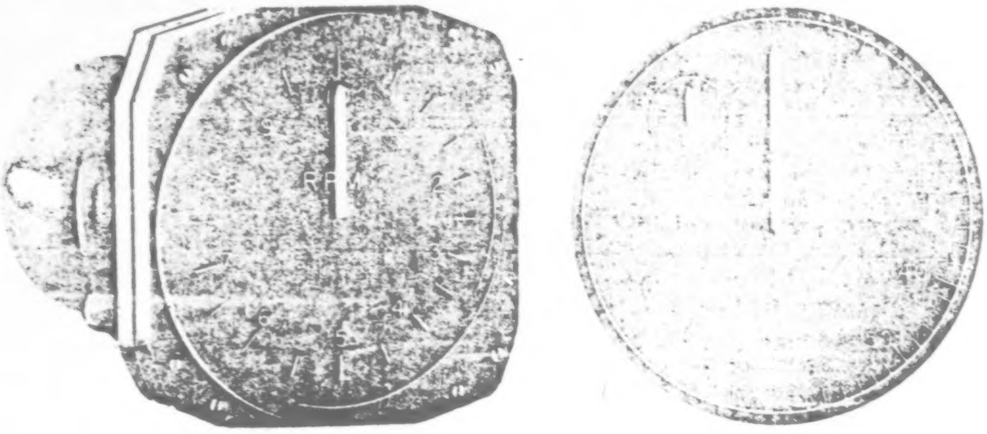

A
M
P
CR
AL
D
A
C
INDICATOR
ESSENTIAL
115V A-C BUS
TURBINE OUTLET
CIRCUIT
BREAKER
CHROMEL (WHITE)
ALUMEL (GREEN)
DUAL THERMOCOUPLE

AN.92

Figure 6-11.–Exhaust gas temperature indicating system.

preference to radial dial indicators, the vertical scale indicator is used to indicate engine performance data, fuel flow, engine speed, exhaust gas temperature, and accelerometer readings. Vertical scale indicators are compact, light in weight, and very easily read.

Basically all vertical scale indicators consist of a vertical thermometer type tape that is actuated by an amplifier, motor, gears, and


(A)

(B)

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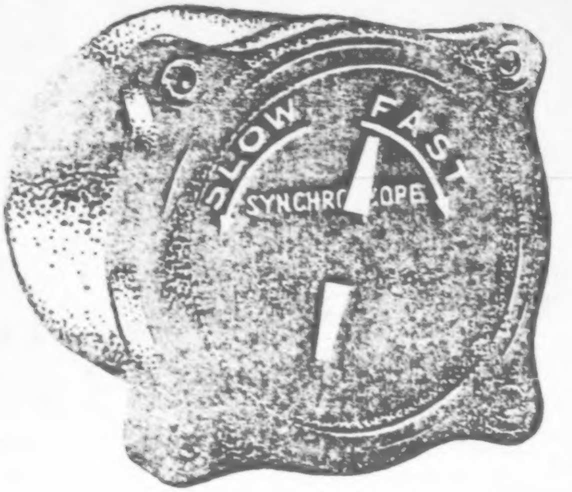
Figure 6-12.–The tachometer. (A) Reciprocating engine type; (B) jet engine type.



AN.94

Figure 6-13.–Synchroscope.

sprockets. Figure 6-16 shows a dual fuel flow vertical scale indicator.

GYROSCOPES

If it were not for the utilization of the properties of a spinning wheel, precise navigation and instrument flying would be very difficult. To realize the importance of this statement,

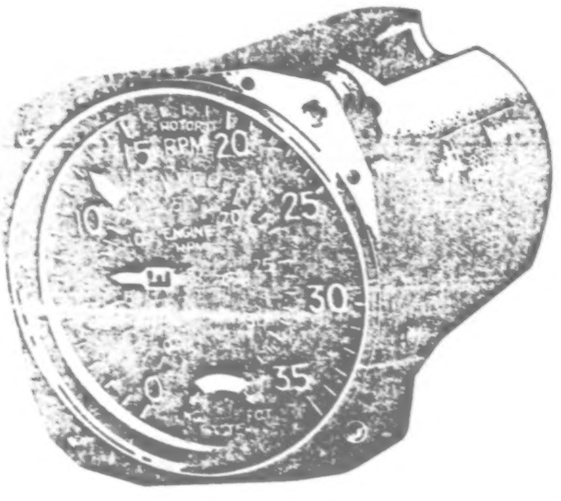


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Figure 6-14.–Helicopter tachometer with synchroscope.

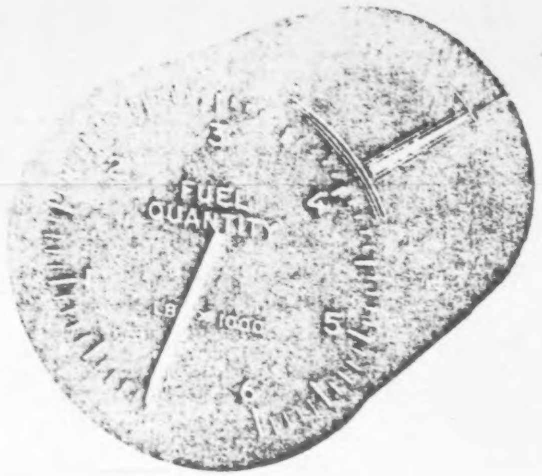

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Figure 6-15.–Fuel quantity indicator.

one has only to consider some of the instruments which utilize the properties of a gyroscope for their operation. The gyro horizon, directional gyro, and turn needle, all of which are described in this chapter, are three of the instruments which are built around a gyroscope.

Any object which can rotate or spin has certain properties while it is spinning which it does not have when it is at rest. These properties are called "gyroscopic," and they are common to all spinning objects, whether the object is a wheel turning on an axle, a propeller spinning about a crankshaft, or a toy top.

In basic form, the gyroscope is a spinning wheel, or rotor, suspended in such a way that the axle is free to rotate about one or both of two axes perpendicular to each other and to the axis of the spin. The assembly in which the wheel is mounted usually consists of a rigid support holding one or two pivoted rings or frames called gimbals. The innermost gimbal supports the rotor.

The fundamental parts of the gyroscope can be illustrated by the demonstration model shown in figure 6-17. Two gimbal rings are employed which provide universal mounting so that the rotor axle can be aligned along any desired direction. The three principal axes about which rotation is possible are: the spin axis (x-x), defined by the rotor axle; the vertical axis, or the line passing through the bearings of the

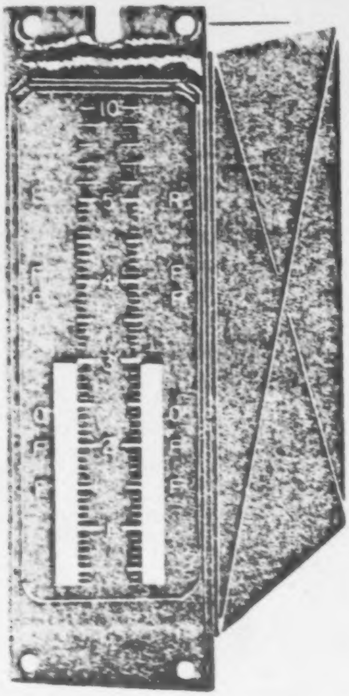

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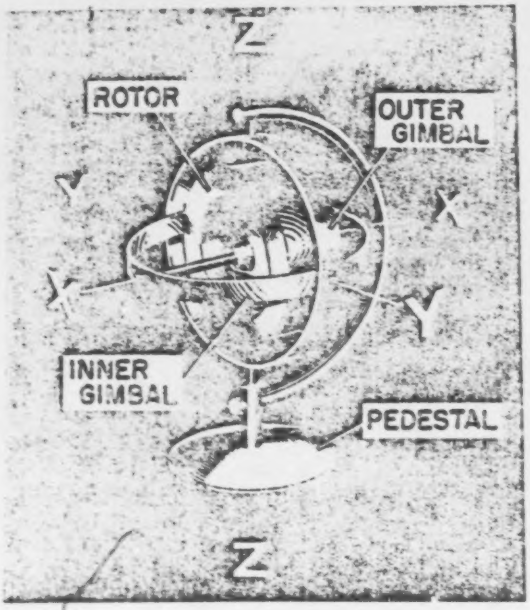
Figure 6-16.–Dual fuel flow vertical scale indicator



AN.98

Figure 6-17.–Elements of a gyroscope.

inner gimbal (y-y); and the horizontal axis (z-z), the line passing through the bearings of the support which suspends the outer gimbal ring. The parts of the assembly are balanced; the point of intersection of the axes coincides with the center of gravity of the rotor; and the pull of gravity does not exert torque, or turning force, on the axis.

Degrees of Freedom

A gyro with universal mounting, as in the case of the demonstration model, is said to have three degrees of freedom: freedom to spin, to turn, and to tilt. If the outer gimbal ring (fig. 6-17) were removed and the inner ring mounted in its place, the gyroscope would then have only two degrees of freedom since only one type of rotation would be possible in addition to spin.

Gyroscopic Properties

Two basic properties of gyroscopes can be illustrated by the use of a simple demonstration model. The first property is rigidity in space (also called stability), and the second is precession. Both of these properties are used in aircraft instrument applications.

Rigidity in space is shown in fundamental form by the demonstration gyroscope in figure 6-18. With the rotor spinning, if the gyroscope is picked up by the frame and rotated about any of the three principal axes, the rotor axle retains the same orientation, pointing in the same direction as in the original position. As long as the rotor spins, any torque applied to the supporting frame alone results only in displacement of the pivoted gimbals and causes no change in the direction of the spin axis.

In aircraft instrument applications, the frame of the aircraft may be considered as corresponding to the support of the demonstration unit. The directional gyro and gyro horizon are constructed in such a way that rotation about the pitch, yaw, and roll axes is not transferred to the rotor elements which therefore remain unchanged in direction and independent of these motions. Hence, the alignment of the spin axis in such a gyro is space stabilized and is suitable for establishing a

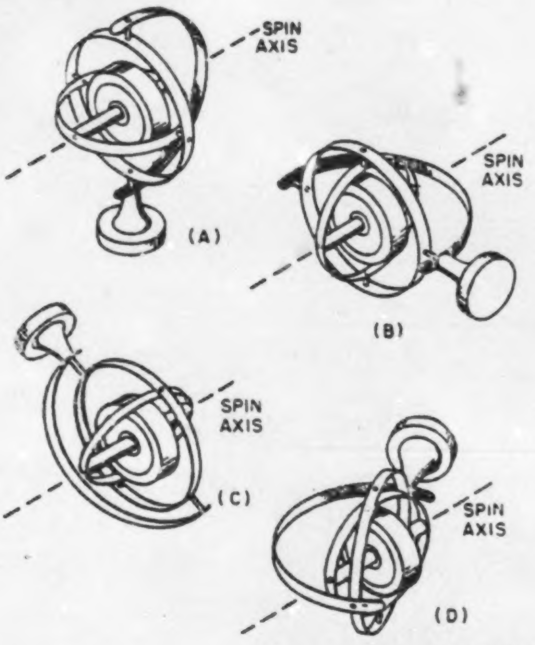


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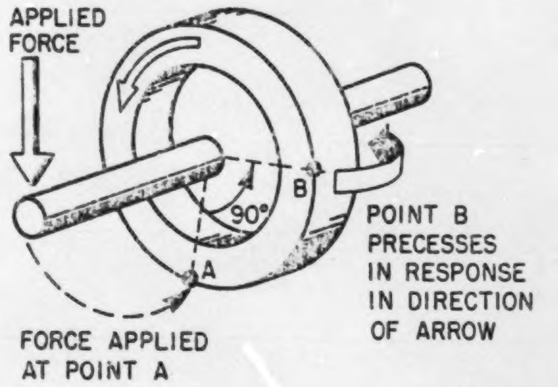
Figure 6-18.–Gyroscopic stability.



AN.101
Figure 6-20.–Direction of precession.

reference from which heading and aircraft attitude may be determined.

Precession, the second of the basic gyro properties, is illustrated in figure 6-19 and 6-20. It has been shown that rotation of the supporting frame of the demonstration gyroscope has no effect upon the alignment of the rotor axle. If, however, a torque is applied directly to the rotor, by pressing down on the inner gimbal ring, for example, the rotor precesses, or rotates, in the manner shown in figure 6-19.

The drawings show the rotor alone with the gimbals and frame removed to clarify the action. The applied force exerts a torque which tends to turn the top of the rotor out of the page toward the reader ((A) of fig. 6-19). The spinning wheel responds with a motion that is the result of two forces: the applied torque and the force of spin directed along the tangent of the wheel. The rotation, or precession ((B) of fig. 6-19), is such that the top of the rotor moves in the plane of the paper, or a plane removed by 90° from the plane containing the applied force. In the final position ((C) of fig. 6-19) the plane of spin is aligned with the plane containing the force. In this position, the precessing torque can no longer act upon the axle and no further precession occurs.

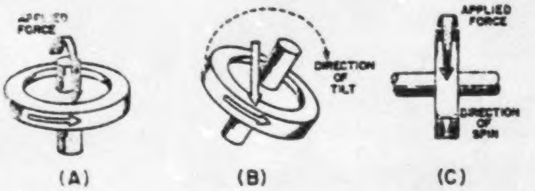


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Figure 6-19.–Precession of a gyroscope rotor.

The direction in which the rotor precesses depends upon two factors: the direction of the precessing force, and the direction of spin of the rotor. This is illustrated in figure 6-20, which also serves as the basis of a simple rule for finding precessional direction. First, determine the direction in which the applied force tends to turn the rotor axle. Next, consider this force as moving in the same plane to a point on the rim of the wheel–such as point A in the drawing. Then imagine that the point is carried 90° around the rim in the direction of spin, or to a point such as B shown in the figure. The rotor responds as though the precessing force were acting at the latter point rather than at the point of actual application. Thus, the rotor precesses about an axis at right angles to the axis about which the applied force acts.

The principle of precession is utilized in the construction of the turn needle. This instrument contains only one gimbal ring and is mounted in such a way that when the aircraft yaws, a force is applied to the rotor, causing it to precess. The amount of precession is proportional to the force applied, which is determined by the rate of turn. A linkage system transmits the action of precession to the turn needle so that the position of the needle accurately indicates the rate of turn.

Gyro Horizon

The gyro horizon provides a direct indication of the aircraft's attitude. It consists of a miniature aircraft, which is fixed in relation to the aircraft, and a gyrostabilized horizontal bar which remains parallel with the earth's horizon and against which the index aircraft appears to move. Within the operating limits of the instrument, the position of the index aircraft relative to the horizon bar gives a direct indication of the aircraft's attitude relative to the actual horizon.

Whenever the aircraft is banked, the index aircraft shows a bank in relation to the horizon bar; the pointer at the top of the instrument indicates the amount of bank. For example, if the aircraft banks to the left, the left wing of the miniature aircraft appears to go down, while the pointer moves to the right. The gyro horizon in figure 6-21 shows four different aircraft flight attitudes, and also the indications displayed by the gyro horizon indicator. To avoid confusion, the pilot should always look at the wings of the aircraft to determine which way he is banked and at the pointer to determine how much he is banked. If the nose of the aircraft is above the horizon, the index aircraft is above the horizon bar, and vice versa.

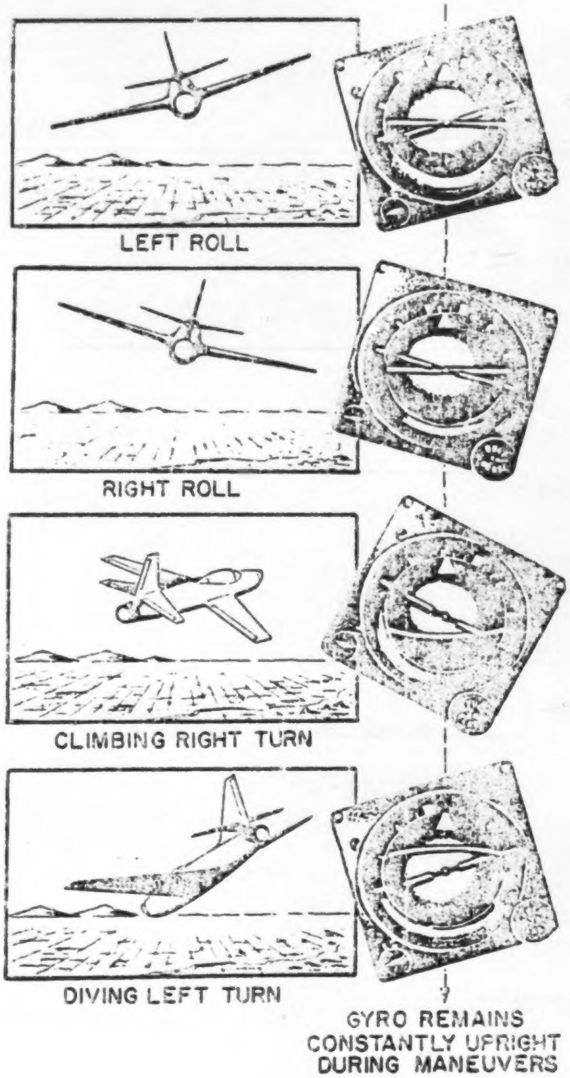

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Figure 6-21.–The gyro horizon indicator, showing roll and pitch indications.

Attitude Horizon Indicator

Another instrument system which uses a gyroscope is the attitude horizon indicator, also referred to as the vertical gyro indicator (fig. 6-22). This system is used to indicate the attitude of the aircraft in roll and pitch, exactly as the gyro horizon does. The gyro horizon has a gyroscope inside the cockpit indicator, but the attitude horizon indicator does not.

In the attitude horizon indicator, the gyroscope is located at some point remote from the cockpit. A sphere which is suspended in gimbals and mechanically driven by servomotors causes the background of the indicator to move. A stationary miniature aircraft mounted on the indicator face serves as the stable reference and is read against a moving horizon line to

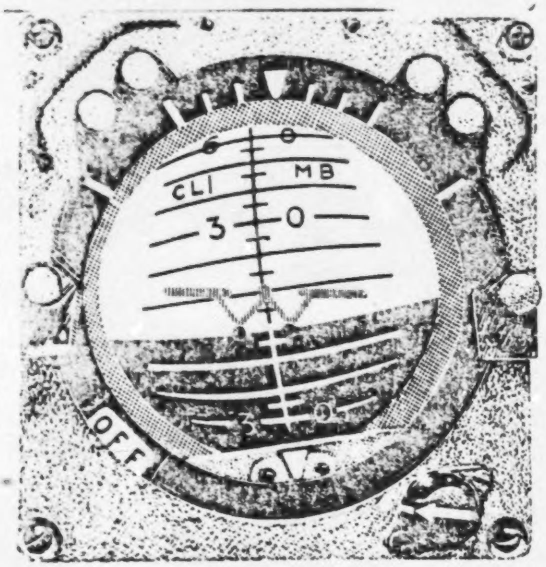


Figure 6-22.–Attitude horizon indicator.
AN. 103

interpret roll and pitch deviations. A power warning flag extends into view from the lower left if the electric power fails or if the navigational computer is not sending accurate signals to the indicator.

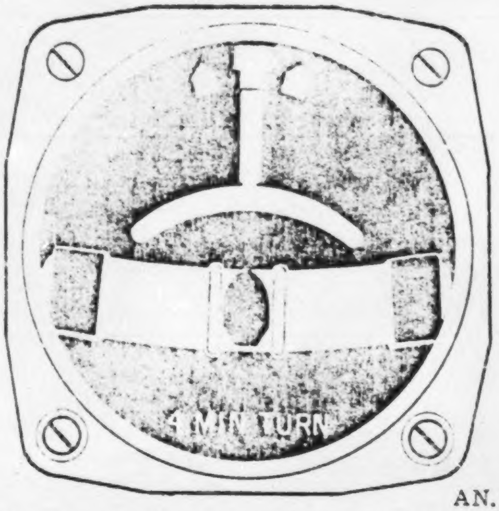
Turn and Bank Indicator

The turn and bank indicator (fig. 6-23) is used to show the correct execution of a bank and turn and to indicate the lateral attitude of the aircraft in straight flight.

A turn and bank indicator is really two instruments mounted as a single unit. The turn indicator part is a gyro mounted in a frame that is pivoted to turn on a longitudinal axis. The direction in which a turn is being made is shown on the dial by a pointer. The distance the pointer moves to the right or left is proportional to the speed of the turn.

The other half of the instrument–the bank indicator–is not a gyro instrument. It consists of a glass ball which moves in a curved glass tube filled with liquid, consisting of 50 percent alcohol and 50 percent glycerin. The tube is mounted horizontally below the center of the dial as shown in figure 6-23.

When the pilot is executing a properly banked turn, the ball stays in the center position. If the ball moves from the center position, it indicates the aircraft is slipping or skidding. Centrifugal force and gravity determine the position at which the ball rests.



AN.104
Figure 6-23.–Turn and bank indicator.

Directional Gyro

The directional gyro is fundamentally a mechanical instrument designed to make it easier to use the magnetic compass. The many errors in the magnetic compass make straight flight and turns to headings extremely difficult, particularly in rough air. The directional gyro is in no way affected by the centrifugal force of turns, rough air, magnetic disturbances, or the geographical position of the aircraft. However, since it is a mechanical instrument it can indicate the aircraft's actual heading only when it is properly aligned with the magnetic compass.

The instrument consists of a circular azimuth ring which is stabilized by a gyroscope and to which is attached a card calibrated from 0° to 360°. A vertical reference wire, or lubber line, crosses the calibration card and serves as a reference for precise readings of directional heading. (See fig. 6-24.)

On modern aircraft, directional information is obtained from the G-2, C-8, MA-1, and MF-1 electrically driven gyrocompass systems.

NAVIGATIONAL INSTRUMENTS

Magnetic Compasses

The magnetic compass is an instrument containing a north-seeking element which, within its

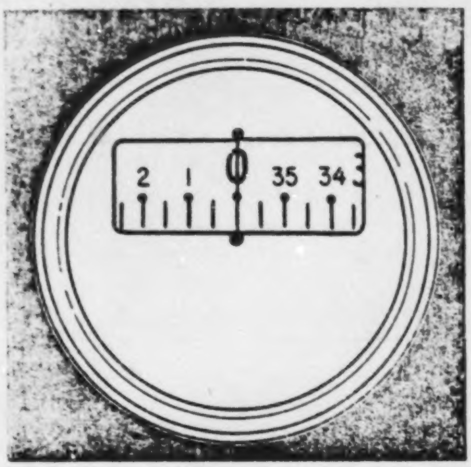


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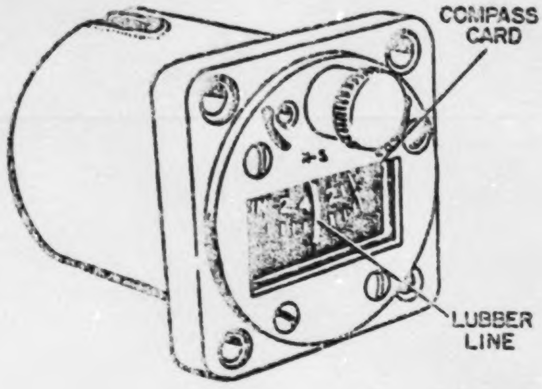
Figure 6-24.–Directional gyro indicator.



AN.106
Figure 6-25.–The direct-reading magnetic compass.

limitations of error, indicates the directional heading of the aircraft in which it is mounted. It consists of a pair of parallel magnetic bars, around which is mounted a calibrated circular compass card. The entire assembly is mounted so that it is free to rotate horizontally. The two magnetic bars thus tend to align themselves with the lines of the earth's magnetic force, with their south poles (or north-seeking poles) pointing to the magnetic North Pole. The calibrations on the compass card are read against a vertical lubber line on the face of the instrument, so that small differences in directional heading can be seen. (See fig. 6-25).

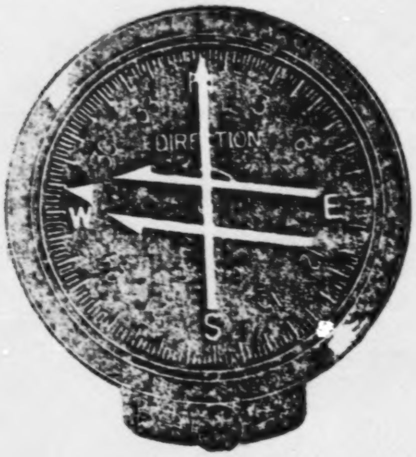
The magnetic compass has a pronounced turning and pitching error, arising from the action of the vertical component of the earth's lines of magnetic force on the tilted magnets during banking, climbing, and diving. These errors appear as tendencies for the card to lag or to overswing the actual turn, and to swing unpredictably in turbulent air. The size of these errors depends upon many factors, among which are geographic latitude, angle of bank or pitch, and yawing.

Errors caused by magnetic deviation and variation must also be considered in interpreting the compass. Magnetic variation is defined as the angle between magnetic north and true north. Variation differs at different points on the earth. If magnetic north and true north coincide, the variation is zero. Magnetic deviation is caused by magnetic materials and turning electrical devices within the aircraft itself. The compass needle primarily seeks alignment with the earth's magnetic field. Deviation varies as the aircraft changes heading due to the magnetic fields created by the equipment within the aircraft. As this creates a different alignment relationship between them and the compass needle, deviation also changes. As an aid in determining deviation for each heading, each compass should have a deviation correction card which indicates the amount of error for each 15 degrees of heading.

The Magnesyn remote-indicating compass system (fig. 6-26) is designed to overcome the problem of changing deviation–one of the main disadvantages of the direct-indicating magnetic compass. (The term "Magnesyn" is a registered trade name of the Bendix Aviation Corporation.)

In this system, the magnetic compass is placed in some remote portion of the aircraft, such as the wing or the tail, where there is a minimum of magnetic interference. The directional compass element is the rotor of the Magnesyn transmitter; the stator is a coil which, through the use of electromagnetic induction, transmits the compass heading to the indicator located on the pilot's instrument panel.

The indicator contains a receiver Magnesyn, including a rotor and stator, and a dial and pointer. The rotor in the indicator always assumes the same position in respect to the



AN.107

Figure 6-26.–The Magnesyn remote-indicating compass indicator.

earth's magnetic field as does the compass element in the transmitter. This rotor is attached to the shaft of the needle on the dial. The indicator itself is not affected by the earth's magnetic influences within the aircraft. Several indicators can be connected to the same transmitter.

The indicator of the remote-indicating compass has a calibrated vertical faceplate and a pointer instead of a compass card and lubber line. Its indications are used in the same manner as those of the direct-indicating magnet compass except that the pilot need not correct for changing deviation. On the face of the instrument there is also a pair of manually adjustable, parallel-grid lines which can be used for reference in maintaining a desired heading. To use the grid lines for this purpose, the index is set to the desired heading by turning the small knob at the bottom of the faceplate. As long as the aircraft's heading is such that the compass pointer remains within the parallel-grid index, the heading is correct. (See fig. 6-26.)

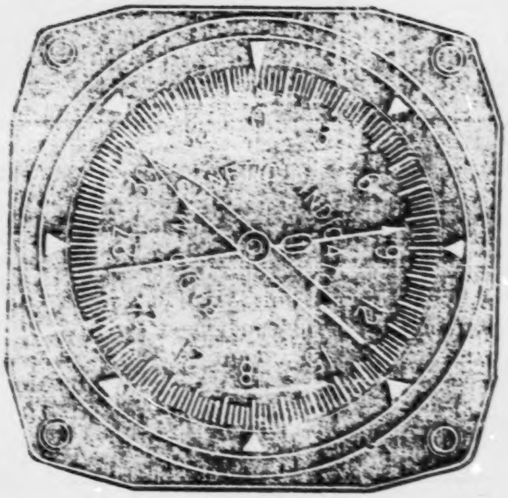
Gyro Compass

The MA-1 compass-controlled directional gyro system is installed in many naval aircraft. This system provides an accurate stabilized indication of aircraft heading through 360° of azimuth and may be operated either as a compass-controlled directional gyro system or as a low-drift free-gyro system. In most installations the MA-1 compass feeds a radio magnetic indicator (RMI). (See fig. 6-27.) On this instrument, the magnetic heading is shown under the top index pip; the needles are indicators for direction finding equipment.

The compass-controlled directional gryo system combines a magnetic compass and a directional gyro to secure the advantages of both. A gyro is inherently very stable for short periods of time, but is subject to long-time drift. A magnetic compass, on the other hand, because of turning and pitching errors wanders continuously about the correct heading. However, the average indication (except over the magnetic polar areas) is very accurate. In this system, the long-period accuracy of the average compass heading is retained as is the short-period accuracy of the gyro, while the short-period oscillation of the compass and the long-time drift of the gyro are eliminated.

HORIZONTAL SITUATION INDICATOR

The newest naval aircraft utilize the horizontal situation indicator to provide the pilot with a visual indication of the navigational situation of the aircraft.



AN.108

Figure 6-27.–The radio magnetic indicator.

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The horizontal situation indicator provides visual presentation of the horizontal or plan view of the aircraft with respect to the navigation situation. It also provides an integrated display of navigation data from various sources and presents these data to the pilot in a symbolic-pictorial display for quick easy assimilation.

Figure 6-28 shows a typical horizontal situation indicator.

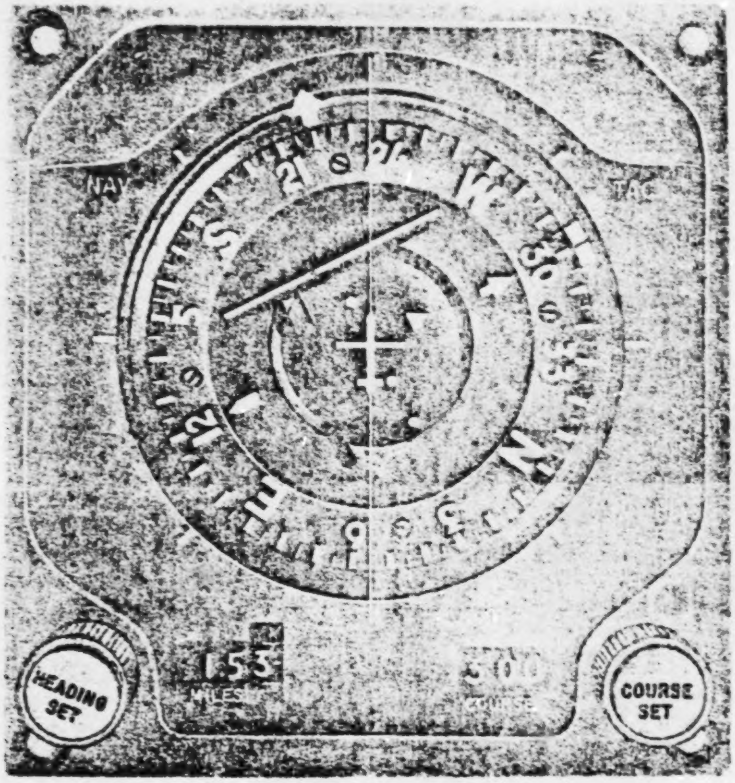

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Figure 6-28.–Horizontal situation indicator.

CHAPTER 10

AIRCRAFT HANDTOOLS AND HARDWARE

Not all of the duties of an Airman are mechanical; however, to a large extent an Airman's skill may be measured by his ability to use handtools and select the proper aircraft hardware. Some of the tools and hardware which the Airman may be required to use are discussed in this chapter.

HANDTOOLS

This section outlines the basic knowledge required in using the most common handtools and measuring instruments employed in aircraft repair work. This information, however, cannot replace sound judgment on the part of the individual. There are many times when ingenuity and resourcefulness can supplement the basic rules. A sound knowledge is required of these basic rules and of the situations in which they do or do not apply. Use of tools may vary, but safety, good care, and proper stowage of tools never vary. For further information concerning the care and use of handtools, consult the Navy Training Course, Basic Handtools, Navpers 10085-A.

PROCUREMENT AND CUSTODY

Handtools are procured by the squadron or activity in accordance with an allowance which is established by the NavAir 00-35QG(Series) allowance lists. This series of allowance lists includes all of the accountable and consumable general support equipment which is required for the maintenance and operation of all types of aircraft at the Intermediate and Organizational levels of maintenance. One section of this allowance list, the Consumable General Support Equipment for all Types, Classes, and Models of Aircraft, NavAir 00-35QG-016, lists the handtools which are usually found in the toolbox issued to the Airman.

The squadron or activity normally procures the tools allotted by these allowance lists and stores them in a toolroom. The toolroom has the responsibility for issuing the tools to the required personnel. This issue may be either permanent or temporary. Permanent custody is usually for an indefinite period of time. Tools issued on temporary custody in most activities must be returned to the toolroom the same day or by the last working day of the week.

When it is necessary for an Airman to have custody of a toolkit, the shop or division chief makes the necessary arrangements with the toolroom for the issue. The toolkit will contain only the tools which are required for the performance of the maintenance tasks which are assigned to the particular shop or division. For example, the tools issued to an Airman who is an AE striker include the tools necessary for the fabrication of electrical assemblies. These tools are not found in the toolkit which is issued to an Airman assigned to the hydraulic shop.

Most toolrooms use a locally prepared form as a checklist when preparing a toolkit. This form when signed by the individual receiving the tools, serves as a custody receipt for the toolroom. A copy is usually given the individual to whom the toolkit is issued. This copy should be kept in the toolkit in a place where it will not be damaged. The copy of the list of tools should be used to maintain a constant check on the contents of the toolkit.

A periodic toolkit inventory is usually required by the activity. Inventory helps the toolroom keep track of the tools which have been issued. Broken or damaged tools are replaced during inventory.

Most handtools are not feasibly repairable. Due to this fact and the low cost (compared to shop tools), they are classed as consumable. However, the activity must pay for replacements. Therefore, it is the duty of each individual to help eliminate the need for replacements. One method of accomplishing this is to insure that all tools are accounted for at the end of each job. The best way to insure that all tools are returned to the kit is to check them off on the copy of the tool inventory which is kept in the toolbox. A tool that has been lost represents a waste of funds; in addition, it is a definite liability. A tool that has been left adrift in an aircraft can jam flight controls, cause shorts in electrical circuits, or become a dangerous missile to crewmembers when the aircraft is launched or performs violent maneuvers.

Broken or worn tools can damage aircraft hardware and parts. They can also cause injury to yourself or others. Therefore, tools should be inspected frequently and the damaged or worn tools turned in to the toolroom for replacement.

DESCRIPTION AND USE

Screwdrivers

Screwdrivers are made to turn screws, and for no other purpose. Figure 10-1 shows several different types of screwdrivers. When using the standard screwdriver, choose one as nearly as possible the same width as the screw which is to be turned. Insure that the blade fits snugly in the slot.

NOTE: A standard screwdriver must fill at least 75 percent of the screw slot. If the screwdriver is the wrong size it cuts and burrs the screw slot, and makes it worthless. A screwdriver with a blade that is the wrong size may slip and damage adjacent parts or structures.

The standard screwdriver is used only where slotted head screws or fasteners are found on aircraft. An example of a fastener which requires the use of a standard screwdriver is the Dzus fasteners which are used to secure the cowling on some aircraft. When turning a recessed head screw, use only the proper recessed head screwdriver, and insure that it is the correct size.

The two types of recessed head screws in common use are the Phillips and the Reed and Prince. Both the Phillips and Reed and Prince recessed heads are optional on several types of screws. As shown in figure 10-1 the Reed and Prince recessed head forms a perfect cross. The screwdriver used with this screw is pointed on the end. The Phillips screw has a slightly larger center in the cross. The Phillips screwdriver is blunt on the end.

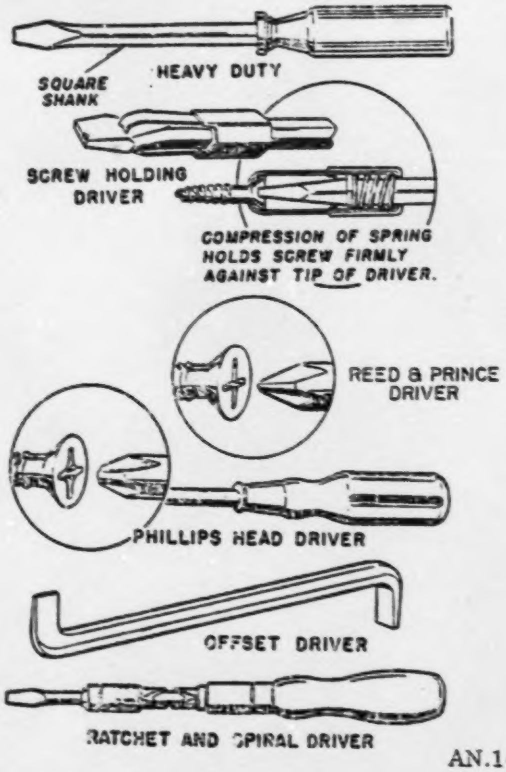

Figure 10-1.—Typical screwdrivers.

CAUTION: The Phillips screwdriver is not interchangeable with the Reed and Prince. The use of the wrong type screwdriver results in mutilation of the screwhead. The Phillips, or Reed and Prince must fill 100 percent of the screw slot.

An offset screwdriver may be used when there is not sufficient vertical space for a standard screwdriver. Offset screwdrivers are constructed with one blade forged in line and the other at right angles to the shank handle. Both blades are bent 90 degrees to the shank handle. By alternating ends, most screws can be seated or loosened even when the swinging space is limited. Offset screwdrivers are made for both standard and recessed head screws.

A screwdriver should not be used as a chisel and should not be used to pry with. Do not use a screwdriver to check an electric circuit. An electric arc will burn the tip and make it useless. In some cases, an electric arc may even fuse the blade to the unit being checked.

When using a screwdriver on a small part, always hold the part in the vise or rest it on a workbench. Do not hold the part in the hand, as the screwdriver may slip and cause serious injury.

Hammers and Mallets

Figure 10-2 shows some of the hammers that the Airman may be required to use. Metal-head hammers are usually sized according to the weight of the head without the handle.

Occasionally it is necessary to use a soft-faced hammer. Soft-faced hammers have a pounding surface made of wood, brass, lead, rawhide, hard rubber, or plastic. These hammers are intended for use in forming soft metals. Soft-faced hammers should not be used for rough work. Striking punch heads, bolts, or nails will quickly ruin this type hammer.

A mallet is a hammerlike tool with a head made of hickory, rawhide, or rubber. It is handy for shaping thin metal parts without denting them. Always use a wooden mallet when pounding a wood chisel or a gouge.

When using a hammer or mallet, chose the one best suited for the job. Insure that the handle is tight. When striking a blow with the hammer use the forearm as an extension of the handle. Swing the hammer by bending the elbow, not the wrist. Always strike the work squarely with the full face of the hammer.

Pliers and Plier Type Cutting Tools

Pliers come in many shapes and sizes. Figure 10-3 shows several different kinds. The combination pliers are handy for holding or bending flat or round stock. Near the hinge are blades for cutting flat or round stock. The long-nosed pliers are less rugged, and break easily if you use them on heavy jobs. Long-nosed pliers commonly called needle-nose pliers are especially useful for holding small objects in tight places and for making delicate adjustments. The round-nosed kind are handy when you need to crimp sheet metal or form a loop in a wire. The diagonal cutting pliers, commonly called "dikes," are designed for cutting wire and cotter pins close to a flat surface. The duckbill pliers and the diagonal cutting pliers are used extensively in aviation for the job of safety wiring.

Here are two important rules for using pliers:

1. Do not make pliers work beyond their capacity. The long-nosed kind are especially delicate. It is easy to spring or break them, or nick their edges. After that, they are practically useless.

2. Do not use pliers to turn nuts. In just a few seconds, a pair of pliers can damage a nut more than years of service.

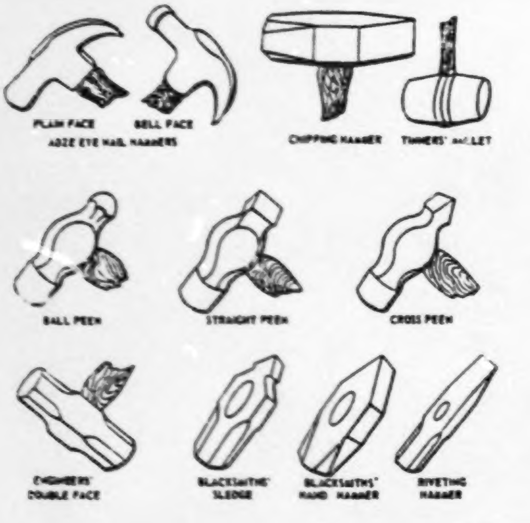
PLAIN FACE
BELL FACE
ADZE EYE NAIL HAMMERS
CHIPPING HAMMER
TINNERS' MALLET
BALL PEEN
STRAIGHT PEEN
CROSS PEEN
ENGINEERS' DOUBLE FACE
BLACKSMITHS' SLEDGE
BLACKSMITHS' HAND HAMMER
RIVETING HAMMER

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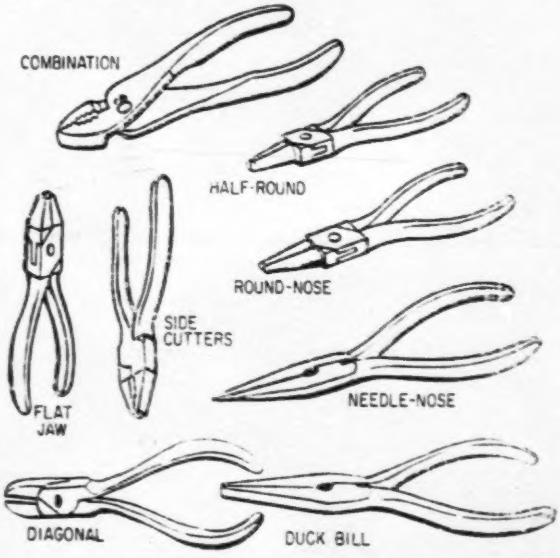
Figure 10-2.—Hammers.


COMBINATION
HALF-ROUND
ROUND-NOSE
SIDE CUTTERS
FLAT JAW
NEEDLE-NOSE
DIAGONAL
DUCK BILL

AN.145

Figure 10-3.—Pliers.

Punches

Figure 10-4 shows several types of punches. Their names explain what they are used for.

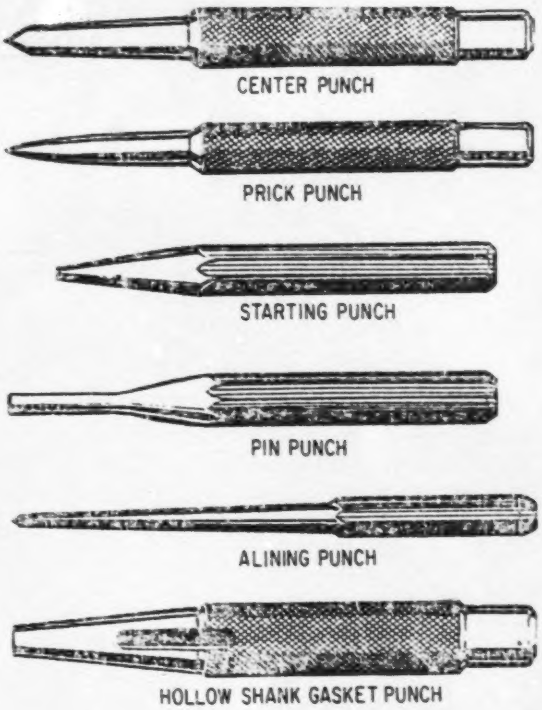
When you use a punch, there are two things to remember:

1. When you hit the punch you do not want it to slip sideways over your work.
2. You do not want the hammer to slip off the punch and strike your fingers. You can eliminate both these troubles by holding the punch at right angles to the work, and striking it squarely with your hammer.

Chisels

A chisel is a hard steel cutting tool which can be used for cutting and chipping any metal softer than the chisel itself. The size of a chisel is the width of its cutting edge. Figure 10-5 shows four different kinds of chisels.

For most metal-cutting work you will use a flat cold chisel. Use a cape chisel for working in narrow grooves and channels. Use the diamond-point chisel for grooving in close places you cannot reach with the cape chisel. The roundnosed chisel, or gouge, is used for cutting oil grooves in bearings, and for chipping out broken bolts from machinery or broken pipes from fittings.


CENTER PUNCH
PRICK PUNCH
STARTING PUNCH
PIN PUNCH
ALINING PUNCH
HOLLOW SHANK GASKET PUNCH

AN.146

Figure 10-4.—Punches.

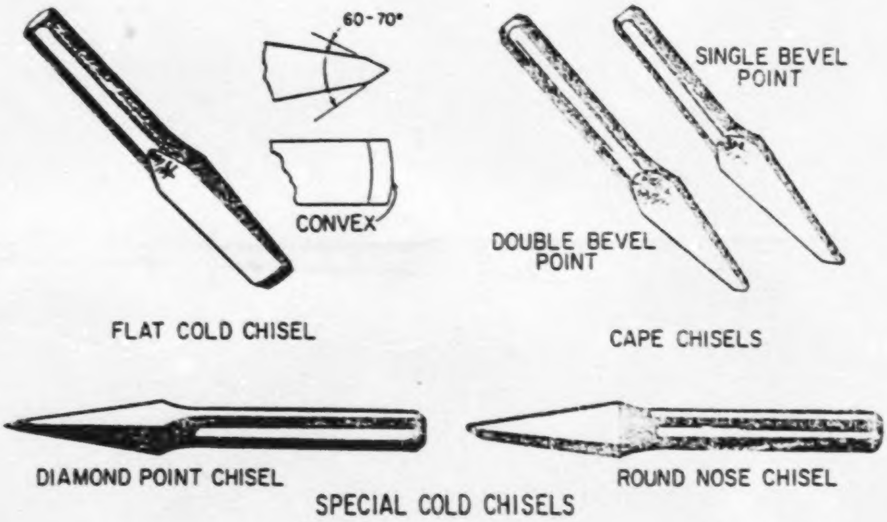

60-70°
CONVEX
FLAT COLD CHISEL
SINGLE BEVEL POINT
DOUBLE BEVEL POINT
CAPE CHISELS
DIAMOND POINT CHISEL
ROUND NOSE CHISEL
SPECIAL COLD CHISELS

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Figure 10-5.—Chisels.

When you use a chisel, hold it firmly in one hand by wrapping your fingers around it. With the other hand, strike the chisel head squarely with a ball-peen hammer.

Notice the neatly ground heads on the chisels in figure 10-5. After repeated pounding, the head will begin to spread out into a mushroom shape. This mushroomed head is dangerous to the user and the bystander, as fragments can fly off the head when pounded and may cause injury. The ragged edges can inflict painful cuts, so grind off the mushroom as soon as it begins to form.

Wrenches

Figure 10-6 shows some of the wrenches you are likely to use.

Most wrenches have just one purpose–to turn bolts, nuts, and studs. Remember these points:

1. Do not use a wrench as a hammer. Wrenches are not made to take a beating.
2. Use a wrench that fits snugly on the object you want to turn. If the wrench fits loosely, it rounds off the corners of the bolt or nut, and then you may have a hard time removing it.

SPANNER WRENCHES.–Sometimes special nuts are made with notches cut into their outer edge. For these nuts a hook spanner is required. This wrench has a curved arm with a lug on the end which fits into one of the notches of the nut. The spanner may be made for just one particular notched nut, or it may have a hinged arm to adapt it to a range of sizes. The U-shaped hook spanner and end spanners are designed to fit into notches cut in either the face or the edge of round nuts. Pin spanners are similar to U-shaped hook spanners, except that they have pins instead of lugs. Figure 10-7 shows both the hook and pin type spanner wrench.

ADJUSTABLE WRENCHES.–Adjustable wrenches are shaped somewhat like open end wrenches except that they have adjustable jaws. The opening is usually set at 22 degrees to the handle and the handle length may vary between 3 to 18 inches. They are used principally on odd shaped nuts or bolts that do not fit any other wrench in the kit.

As there is generally a little "give" to the adjustable jaw, the fit must be very tight or the wrench will slip. Whenever possible the wrench should be placed on the nut so that the pulling force is applied to the stationary side of the handle, rather than the movable jaw. Adjustable wrenches can withstand greater force when used in this manner.

Adjustable wrenches should be cleaned occasionally in a solvent and a light oil applied to the knurl and the sides of the adjustable jaw. They also should be inspected often for cracks which might result in failure of the wrench.

ALLEN WRENCHES.–Most headless setscrews are the Allen type and require an Allen wrench. Allen wrenches are made of tool steel and are L-shaped. (See fig. 10-6.) The most common type is hexagonal and fits the hexagon

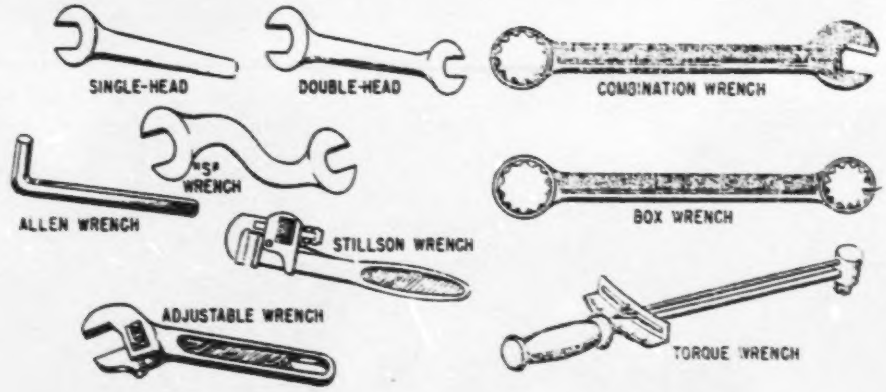

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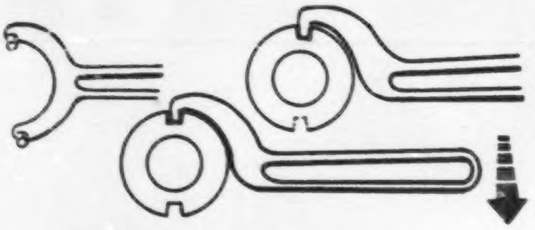
Figure 10-6.–Wrenches.



AN.149

Figure 10-7.–Spanner wrenches.

socket in the screw. These wrenches come in various sizes according to the size of the socket in the setscrew. Be sure to use a wrench of exactly the right size.

SOCKET WRENCHES.–Few tools have saved more time and effort than the socket wrench. Socket wrench sets have handles common to all sizes of sockets. The sockets have 8 or 12 points, thus making it easy to seat the socket onto the nut. Sockets are usually furnished in sets for a range of different size nuts. The sets are available in 4 classes, designated by the size of the square on the drive end. Standard drive sizes are 1/4-, 3/8-, 1/2-, and 3/4-inches. Figure 10-8 shows part of a socket set.

The sockets are made of a very strong steel alloy, and therefore can be very thin. This is a definite advantage when working in close quarters. Deep sockets are designed for such use as removing spark plugs.

There are various handles furnished with each socket set. The most important of these are the ratchet and the speed handle.

A universal joint is furnished with each socket set. By inserting the universal between the handle and the socket it is possible to work in almost inaccessible spaces.

It is important to keep these socket wrenches clean. This applies particularly to the ratchet assembly. Grit can sift into the mechanism easily and do serious damage. The handle and sockets can be broken if a piece of pipe is used to obtain additional leverage, or by hammering on the handle. If more pressure is required, wrenches with larger drives should be used.

Files

A file is a cutting tool with a number of cutting edges or teeth on its surface. Figure 10-9 names the parts of the file. It shows files of various shapes in cross section.

Figure 10-9 does not show the file handle. Never use a file unless it has a tight-fitting handle. If you use a file without a handle and it hits something solid on its forward stroke, the tang can dig a hole in the palm of your hand.

Files are named by their shape, size, and cut. The word cut refers both to the kind of teeth and to their coarseness. The cut of files is classified, according to the kind of teeth, into single, double, and rasp cut. The cut is also

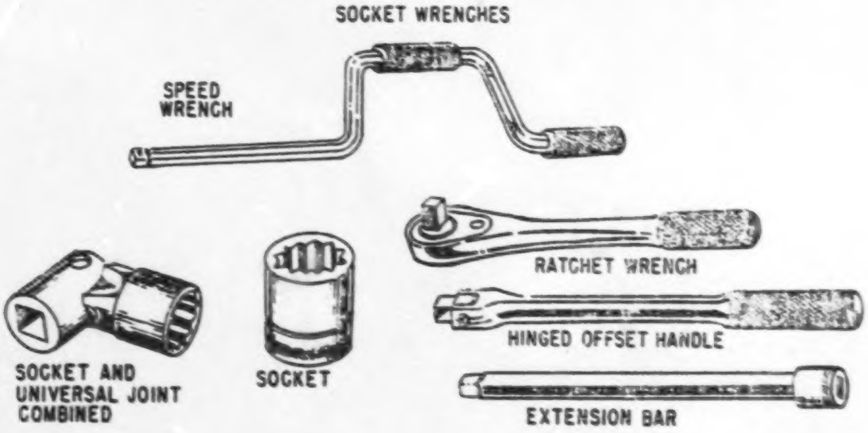


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Figure 10-8.–Socket wrench set.

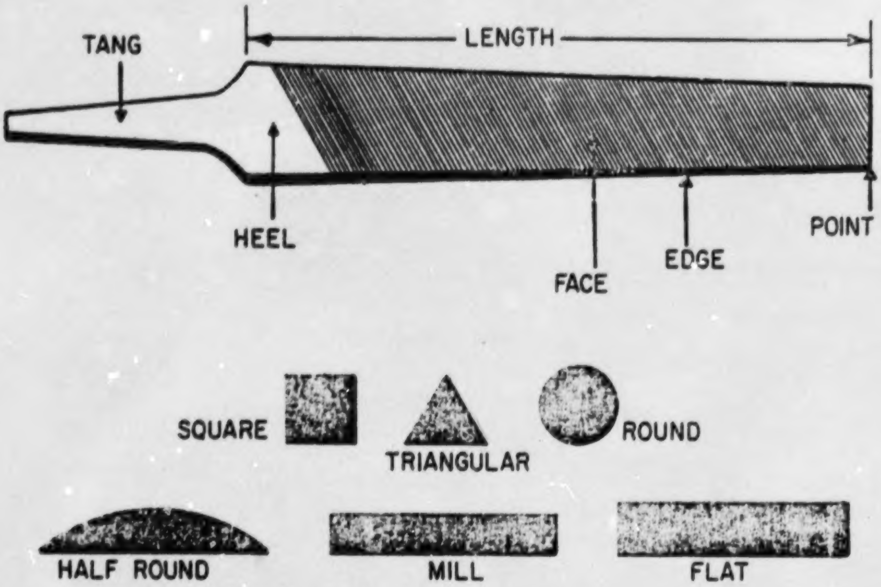

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Figure 10-9.–Shapes of files.

classified according to coarseness into smooth, second cut, and bastard. (There are a few files coarser than bastard; they are called coarse or rough. There are a few finer than smooth; they are called deadsmooth.)

Be sure to pick the right file for the work you are doing. For a quick coarse cut, use a rough or bastard file. For smoother or more delicate work, use a finer file.

Do not use a new file on new cast iron or steel. The scale on new iron and steel is very hard, and quickly dulls your file. Do not use a coarse toothed file on thin stock. Remember that you have to have at least two cutting teeth on the stock at all times. If you have to file lead or solder, use an old, coarse file that is not good for anything else. (It is almost impossible to clean lead out of file teeth.) A neat trick is to rub chalk over a file to deter lead from sticking to it.

Figure 10-10 shows the difference between single cut and double cut, and the difference between the three principal grades of coarseness.

Kits of small files, often called swiss pattern files, are made for work on delicate units such as instruments. Each kit includes eight or more assorted sizes and shapes. These files are thin and brittle and are easily broken.

Hacksaws

A hacksaw is used for sawing metal. Figure 10-11 shows the two different types of hacksaw frames; the saw at the top of the picture has a pistol-grip handle; the other one has a straight handle. Most hacksaws, like the pistol-grip saw in figure 10-11, are adjustable to take blades of various lengths.

A hacksaw blade is made of hardened steel; it will cut any common metal except another piece of hardened steel. The frame that holds the blade is deep enough to let you cut through any ordinary thickness of metal. The coarseness of the blade is designated by the number of teeth per inch.

The blade should be well tightened in the frame, with the rake of the teeth away from the handle. When you use a hacksaw, bear down on the forward stroke, and be careful not to bend the blade sideways. To saw quickly without tiring, keep up a steady pace of about 50 strokes a minute. Figure 10-12 shows the right and wrong way to begin a cut.

You need some practice before you can judge how much pressure to put on the saw. If you try to force it by using too much pressure, you do not saw any faster, and you quickly dull

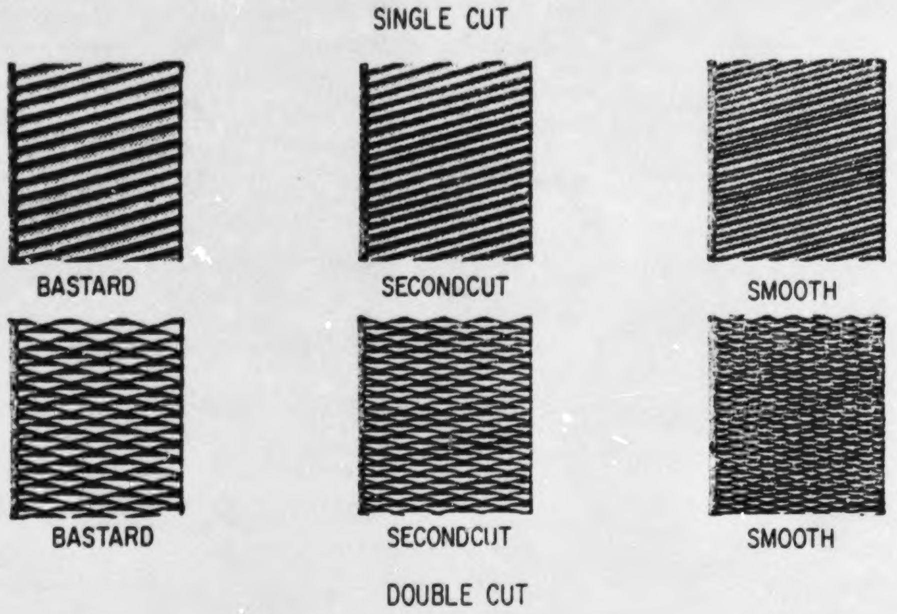

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Figure 10-10.–Grades of file teeth.

the saw teeth. On the other hand, you can dull the blade by using too little pressure on your first cut, especially on iron and steel. Why? Because iron and steel stock is usually covered with a thin scale of rust, much harder than the metal itself. If you just push the teeth over the scale without cutting through it, you ruin the teeth.

Use a fine blade for light or soft metal. Be sure the blade is fine enough so that at least two teeth rest on the work at all times. For example, if you are cutting stock one-sixteenth inch thick, use a blade with at least 32 teeth per inch. If you use a coarser blade, the teeth will probably break. Remember, when you are sawing tubing, go by the thickness of the tube wall, not by the thickness of the tube.

Hand Snips

There are several kinds of hand snips, each of which serves a different purpose. (See fig. 10-13.) In common use there are straight, curved, hawks bill, and aircraft snips. Straight snips are used for cutting straight lines when the distance is not great enough to use a squaring shear and for cutting the outside of a curve. The other types are used for cutting the inside of curves of radii. Snips should never be used to cut heavy sheet metal.

Aviation snips are designed especially for cutting heat-treated aluminum alloy and stainless steel. They are also adaptable for enlarging

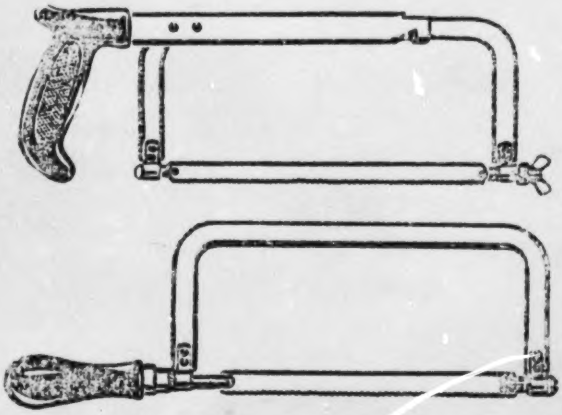

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Figure 10-11.–Hacksaws.

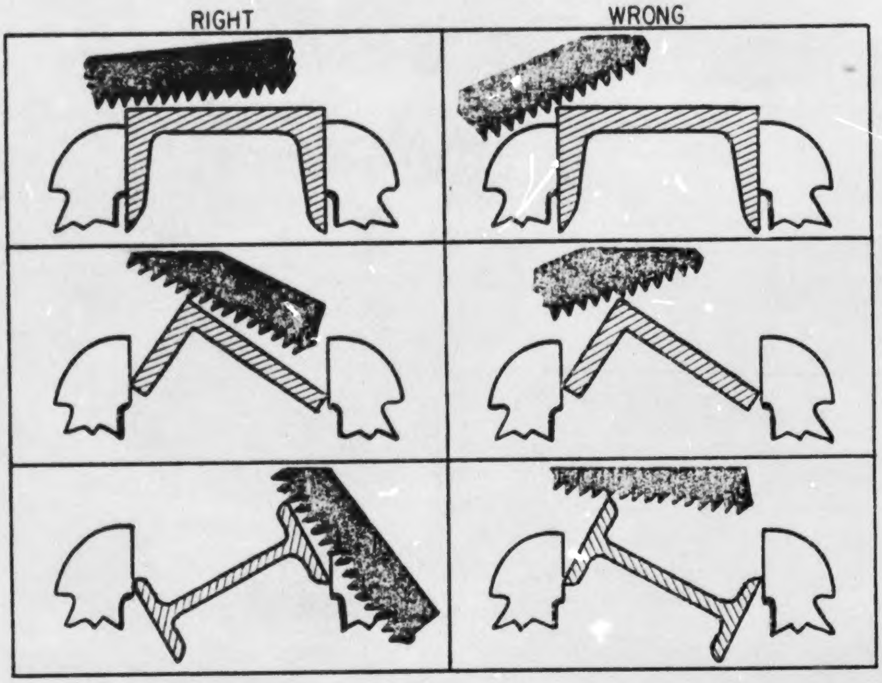

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Figure 10-12.–Starting hacksaw cuts.

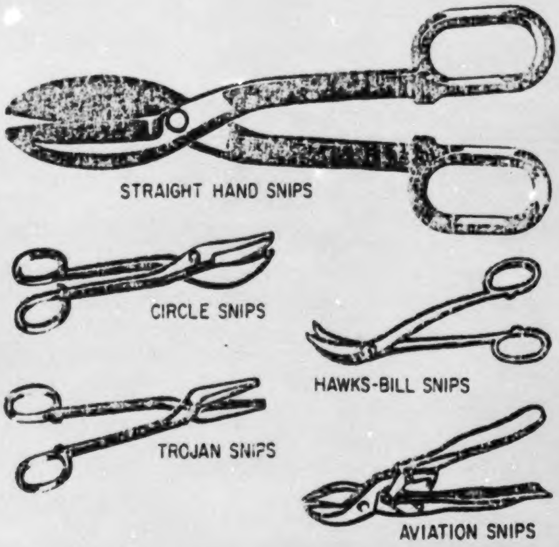
small holes. The blades have small teeth on the cutting edges and are shaped for cutting very small circles and irregular outlines. The handles are of the compound leverage type, making it possible to cut material as thick as 0.051 inch. Aviation snips are available in two types, those which cut from right to left and those which cut from left to right.

Unlike the hacksaw, snips do not remove a certain width from the material when the cut is made, but minute fractures often occur along the cut. Therefore, cuts should be made about one thirty-second inch from the layout line and finished by hand filing down to the line.

Drills

A drill is a pointed tool that is rotated to cut holes in material. It is made of a cylindrical hardened steel bar having from one to four straight or spiral flutes (grooves) running its length, and a conical point with cutting edges formed by the ends of the flutes.

TWIST DRILLS.–Because of its ability to withstand heat without losing its temper, high-



AN.155

Figure 10-13.–Snips.

speed steel is generally used for twist drills. (See fig. 10-14.) These drills are available with either two, three, or four flutes. Drills with two flutes are used for most drillings; those with three or four are used principally to follow smaller drills or to enlarge holes.

The principal parts of a twist drill are the shank, the body, and the point. The drill shank is the end that fits into the chuck of a hand or power drill. The two shank shapes most commonly used in hand drills are the straight shank and the square or bit stock type shank. The straight shank is generally used in hand, breast, and portable electric drills; the square shank is made to fit into a carpenter's brace. Tapered shanks are generally used in machine shops.

The metal column forming the core of the drill is the body. The body clearance area lies just back of the margin, slightly smaller in diameter than the margin, to reduce the friction between the drill and the sides of the hole. The angle at which the drill point is ground off is the lip clearance angle. On standard drills used to cut steel and cast iron, the angle should be 59 degrees from the axis of the drill. For faster drilling on soft materials, sharper angles are used. Consult Basic Handtools, NavPers 10085-A, for more detailed information on the lip clearance angle and sharpening of drills.

Before and after use, the cutting edge of each drill should be inspected for cracks, chips, or burrs. Small-size drills should not be used for reaming holes to a larger size. They are not made to withstand a bending force and therefore snap easily. The material to be drilled should be properly supported and clamped before work is begun. The drill and material should be kept cool and well lubricated with cutting fluids.

There are generally three types of drills that are used in aviation. They are the hand drill, electric drill, and the pneumatic drill. The hand drill is used for drilling holes up to one-fourth inch in diameter in metal. Electric and pneumatic drills are used for drilling larger holes, although they are used considerably for drilling small holes. They are time saving and much easier to handle.

Drills are classified in three ways: By fractions, by letters, or by numbers. Fractionally, they are classified by sixteenths of an inch (from 1/16 to 3 1/2 in.), by thirty-seconds (from 1/32 to 2 1/2 in.), or by sixty-fourths (from 1/64 to 1 1/4 in.). For a more exact measurement a letter system is used with decimal equivalents: A (0.234 in.) to Z (0.413 in.). The number system of classification is most accurate: No. 80 (0.0314 in.) to No. 1 (0.228 in.).

Countersinks are used to bevel the edge of a drilled hole. The type of countersink shown in figure 10-15 is the most commonly used. Its construction is similar to that of the twist drill. There are three cutting edges which are taper ground to the angle marked on the body. The countersink selected should have a lip angle corresponding with the screw or rivet to be used.

When using a countersink to bevel a hole, care must be taken not to remove an excessive amount of material as this results in weakening the work.

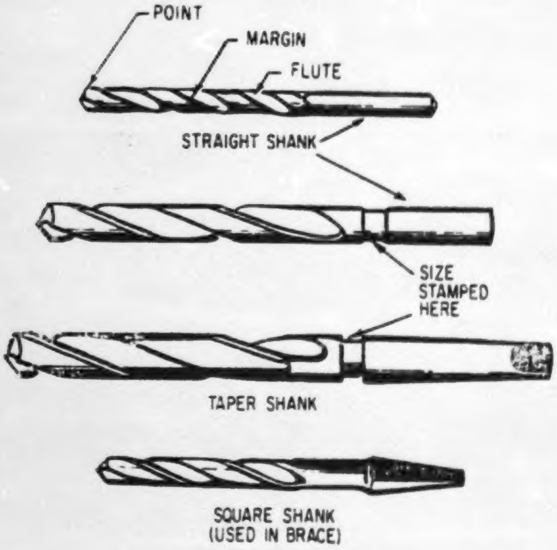


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Figure 10-14.–Drills.

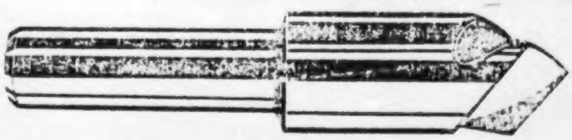

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Figure 10-15.–Countersink.

Measuring Tools

In all phases of your work as an Airman, you need and use measuring tools or measuring instruments. Each specialty has measuring tools designed for the particular specialty, but there are a few common tools that everyone should know how to use.

RULES.–Most of the common measuring tools are designed to measure length or distance from one point to another. The tools designed for this purpose are usually divided into inches or feet and parts of inches or feet. An example of this type of measuring tool is the 1-foot or 12-inch steel rule (fig. 10-16). Notice that on each of the edges of this rule the inch is divided into different fractional parts. Thus, the same rule provides four separate scales graduated in 8ths, 16ths, 32nds, and 64ths. You may even use a scale which has all of these divisions on one edge, so you should study the divisions and be able to use either type.

Consult Basic Handtools, NavPers 10085-A, for the correct use and reading of the rules shown in figure 10-16.

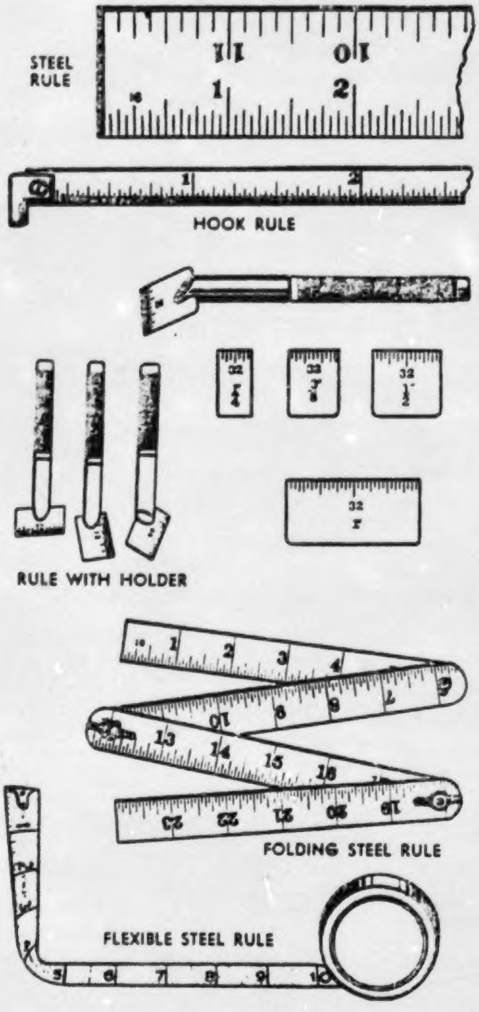

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Figure 10-16.–Rules.

DIVIDERS.–When using a steel rule, you sometimes have to transfer measurements from a piece of work to a rule or to transfer a measurement from the rule to the work because of space requirements or for some other reason. This is done with dividers (fig. 10-17.) They can be adjusted for accurate measuring and they fit into places that are too small for the tape or rule. Most toolbox type dividers can be used for measurements up to 4 or 5 inches, and for scribing arcs or circles with diameters of 8 to 10 inches.

CALIPERS.–All the measuring tools mentioned so far are used for measuring flat surfaces. You sometimes have to measure the diameter of a hole or a piece of round stock. In this situation you should use one of the various types of calipers shown in figure 10-18. Basic Handtools, NavPers 10085-A, explains how to use these various types of calipers. The micrometer or mike is used for very accurate measurements.

SQUARES.–Convenient measuring tools called squares are shown in figure 10-19. The four pictured here are the steel square, the double square, the try square, and the combination square. This last square consists of a graduated steel rule with an accurately machined head. The two edges of the head provide for measurements of 45° and 90°, respectively.

Combination sets are necessary when measuring a variety of angles. They consist of a steel rule and three heads. The square head is the same as provided with the combination square. This combination set also has a protractor head for measurement of any desired angle and center head to center round stock. The protractor head may be set at any desired angle by loosening a clamp screw and turning the head.

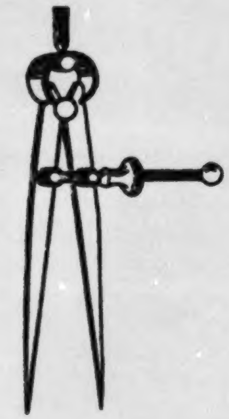

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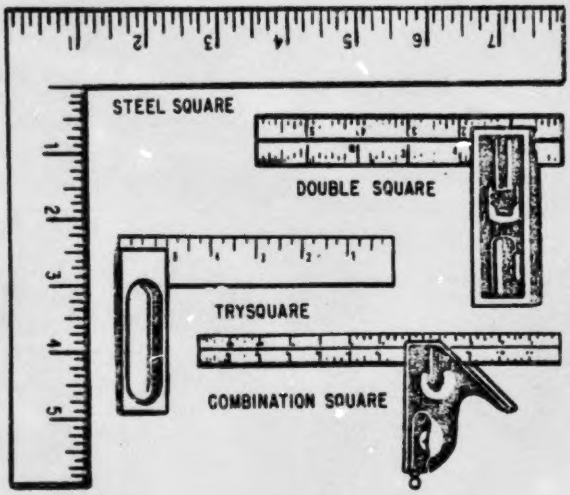
Figure 10-17.–Dividers.



AN.161

Figure 10-19.–Squares.

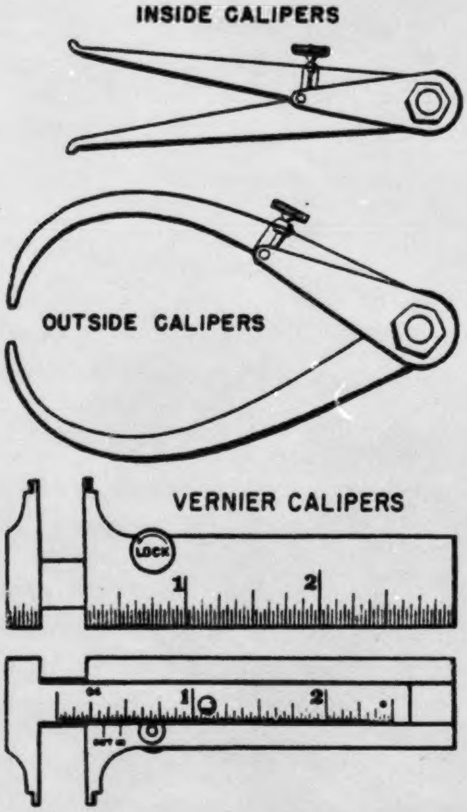


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Figure 10-18.–Calipers.

SPECIAL TOOLS

For each aircraft there are Maintenance Instructions Manuals published by the manufacturer to be used as reference in all types of maintenance on a particular aircraft. Special tools for the aircraft can be found in these manuals; for example, special tools for the P-3A aircraft are listed in table 11-1 of Section XI of General Information and Servicing, NW 01-75PAA-2-1, a part of the Maintenance Instructions Manual for the P-3A. Table 11-1 tells where the use of these special tools can be found; for example, Section III of Landing Gear, NW 01-75PAA-2-2.2, pertains to the main landing gear shock strut tools (special tools). The manual illustrates the tools in figure 3-35 and gives their uses in paragraph 3-131.

The maintenance of special tools should be handled by skilled personnel or the tools returned to the factory for maintenance. Accounting for the special tools should be rigid because there are not many available to the worker.

TORQUE WRENCHES

There are times when a nut, bolt, or screw must be set at a certain tightness; therefore, a torque wrench is used. This precision tool has a torque indicating handle and appropriate adapter or attachments. It measures the amount of turning or twisting force applied to a nut, bolt, or screw. Torque wrenches measure torque in inch-pounds or foot-pounds.

The three most commonly used torque wrenches are the deflecting beam, dial indicating, and micrometer setting types (fig. 10-20). When using the deflecting beam and the dial indicating torque wrenches, the torque is read visually on a scale mounted on the handle. An attachment is put on the nut, bolt, or screw, the wrench set to the attachment, and the handle pulled in the tightening direction until the desired torque is reached on the dial.

To use the micrometer setting type, unlock the grip and adjust the handle to the desired setting on the micrometer type scale, then relock the grip. After installing the required adapter to the handle, place the wrench assembly on the nut, bolt, or screw and pull in the tightening direction with a steady, smooth motion. When the torque applied reaches the value set on the handle, the handle will release and move freely for a short distance. This release and the free travel are easily felt so there is no doubt when the torquing process is complete.

To assure obtaining the correct amount of torque on the fasteners, all torque wrenches must be tested at least once a month or oftener if use indicates it is necessary.

The following precautions should be observed when using torque wrenches:

1. Do not use the torque wrench for anything except to measure torque.
2. When using the micrometer setting type, do not move the setting handle below the lowest setting. The handle should be placed in the lowest setting before returning to storage.
3. Do not use the torque wrench to apply greater amounts of torque than its rated capacity.
4. Do not use the torque wrench to break loose bolts, nuts, or screws which have been previously tightened.
5. Never store a torque wrench in a toolbox or any other area where it may be damaged.

AIRCRAFT HARDWARE

Aircraft hardware is the term used to describe the various types of fasteners and miscellaneous other small items used in the manufacture of Navy aircraft.

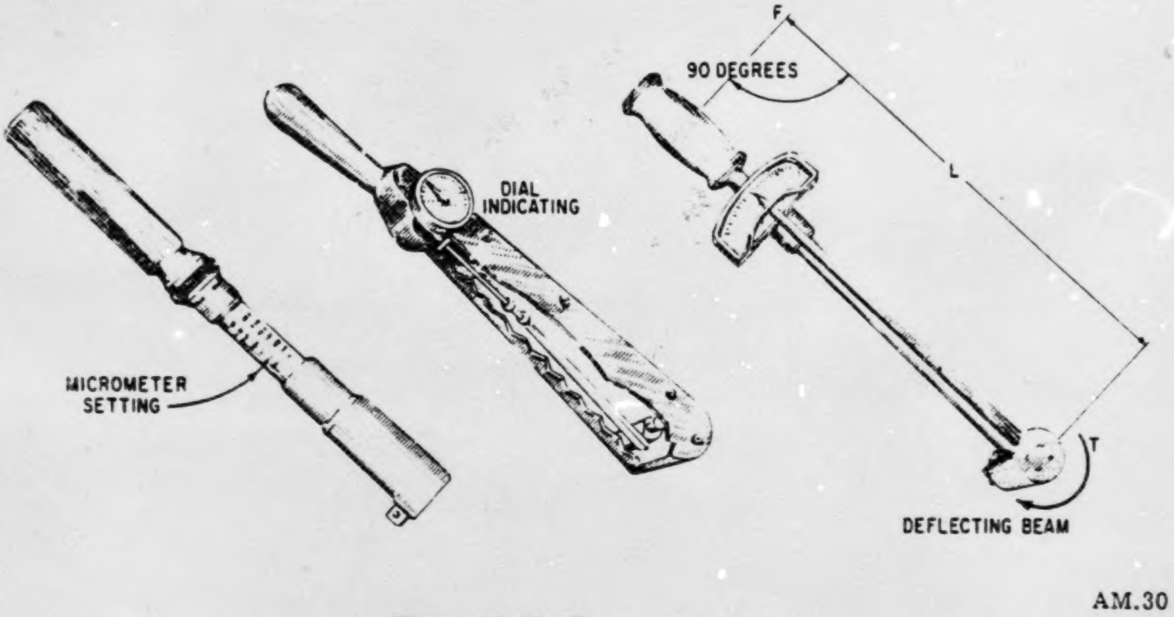

Figure 10-20.–Torque wrenches.

The importance of aircraft hardware is often overlooked because of its small size; however, the safe and efficient operation of any aircraft is greatly dependent upon the correct selection and use of aircraft hardware.

This section describes the various types of threaded fasteners, quick release fasteners, rivets, control cables, push-pull tubes, torque tubes, and electrical wiring.

Since it is important to insure that these items of aircraft hardware remain tightly installed on the aircraft, proper safety methods are also discussed in this section.

IDENTIFICATION

Most items of aircraft hardware are identified for shop use by their specification number or trade name. Threaded fasteners and rivets are usually identified by AN (Air Force-Navy), NAS (National Aircraft Standard), and MS (Military Standard) numbers. Quick release fasteners are usually identified by factory trade names and size designations.

For procurement of aircraft hardware from supply, the specification numbers and the factory part numbers are changed into Federal stock numbers. This is done by using a part-number cross-reference index.

THREADED FASTENERS

Although thousands of rivets are used in aircraft construction, many parts require frequent dismantling or replacement, making it more practical to use some form of threaded fastener. Furthermore, some joints require greater strength and rigidity than can be provided by riveting. Manufacturers solve this problem by using various types of screws, bolts and nuts.

Bolts and screws are similar in that both have a head at one end and a screw thread at the other, but there are several differences between them. The threaded end of a bolt is always relatively blunt, while that of a screw may be either blunt or pointed. The threaded end of a bolt must be screwed into a nut, but the threaded end of the screw may fit into a nut or other female type arrangement, or may fit directly into the material being secured. A bolt has a fairly short threaded section and comparatively long grip length (the unthreaded part), whereas a screw may have a longer threaded section and no clearly defined grip length. A bolt assembly is generally tightened by turning its nuts, and its head may or may not be designed to be turned, while a screw is always designed to be turned by its head. Another minor but frequent difference between a screw and a bolt is that a screw is usually made of lower strength materials.

Classification of Threads

Threads on aircraft bolts and screws are of the American National Standard type. This standard contains two series of threads—national coarse (NC) and national fine (NF) series. Most aircraft threads are of the NF series.

There are five classes of threads. The class of a thread indicates the tolerance allowed in manufacturing. NOTE: Class of threads is discussed in more detail in Blueprint Reading and Sketching, NavPers 10077-B.

Threads are also produced in right-hand and left-hand types. A right-hand thread advances into engagement when turned clockwise. A left-hand thread advances into engagement when turned counterclockwise.

Thread Sizes

Threads are sized by both the diameter and number of threads per inch. The diameter is designated by screw gage number for sizes up to one-fourth inch, and by nominal size for those one-fourth inch and larger. Screw gage numbers range from 0 to 12, except that numbers, 7, 9, and 11 are omitted.

Identification of Threads

Threads are designated by the diameter, number of threads per inch, thread series, and class in parts catalogs, on blueprints, and on repair diagrams.

For example, No. 8-36NF-3 indicates a No. 8 size thread, 36 threads per inch, national fine series, a class 3 thread. Also 1/4-20NC-3 indicates a 1/4-inch thread, 20 threads per inch, national coarse series, and a class 3 thread. A left-hand thread is indicated by the letters LH following the class of thread.

Aircraft Bolts

Most bolts used in aircraft structures are either general-purpose, internal-wrenching, or close-tolerance AN (Air Force-Navy), NAS (National Aircraft Standard), or MS (Military Standard) bolts. In certain cases, aircraft manufacturers are compelled to make bolts of different dimensions or greater strength than the standard types. Such bolts are made for a particular application and it is of extreme importance to use like bolts in replacement. Such special bolts are usually identified by the letter S stamped on the head.

AN bolts come in three head styles–hex-head, clevis, and eyebolt (fig. 10-21). NAS bolts are available in hex-head, internal-wrenching, and countersunk head styles. MS bolts come in hex-head and internal-wrenching styles.

IDENTIFICATION.–Head markings indicate the material of which standard bolts are made and whether or not the bolt is classed as a close-tolerance bolt (See fig. 10-21.) Additional information, such as bolt diameter, bolt length, and grip length may be obtained from the bolt part number.

In the bolt part number AN3DD6A, for example, the AN designates that it is an Air Force-Navy Standard bolt, the 3 indicates the diameter in sixteenths of an inch (3/16), the DD indicates the material is 2024 aluminum alloy, the 6 indicates the grip and length (as taken

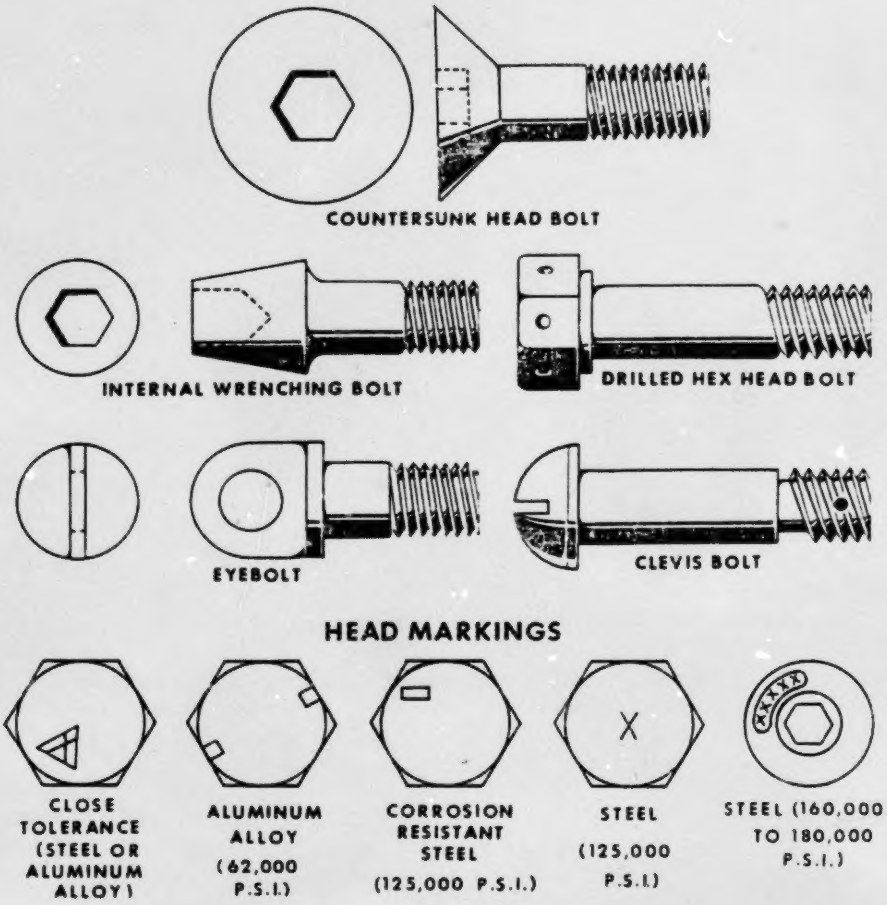
COUNTERSUNK HEAD BOLT
INTERNAL WRENCHING BOLT
DRILLED HEX HEAD BOLT
EYEBOLT
CLEVIS BOLT
HEAD MARKINGS
CLOSE TOLERANCE (STEEL OR ALUMINUM ALLOY)
ALUMINUM ALLOY (62,000 P.S.I.)
CORROSION RESISTANT STEEL (125,000 P.S.I.)
STEEL (125,000 P.S.I.)
STEEL (160,000 TO 180,000 P.S.I.)
XXXXX

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Figure 10-21.–Types of bolts and bolthead markings.

from special tables), and the A indicates that the shank is not drilled for cotter pin safetying. Absence of the letter indicates that the shank is drilled.

The letter C in place of the DD indicates corrosion-resisting steel, and the absence of the letter indicates cadmium-plated steel. The letter H preceding the 6 indicates the head is drilled for safetying with wire.

Nuts

Aircraft nuts may be divided into two general groups–nonself-locking and self-locking nuts. Nonself-locking nuts are those which must be safetied by external locking devices, such as cotter pins, safety wire, or locknuts. Self-locking nuts contain the locking feature as an integral part.

NONSELF-LOCKING NUTS.–The most common of the nonself-locking nuts are the castle nut, the castellated shear nut, the plain nut, and the wing nut. Figure 10-22 illustrates these nonself-locking nuts.

The castle nut is used with drilled-shank AN hex-head bolts, clevis bolts, or studs. It is designed to accommodate a cotter pin or lock-wire for safetying.

The castellated shear nut is used on such parts as drilled clevis bolts, and threaded taper pins that are normally subjected to shearing stress only. It must not be used in installations where tension stresses are encountered.

The plain hex nut has limited use on aircraft structures. It requires an auxiliary locking device such as a checknut or a lockwasher.

The wingnut is used where the desired tightness can be obtained by the fingers, and where the assembly is frequently removed. Wingnuts are commonly used on battery connections.

SELF-LOCKING NUTS.–There are two general types of self-locking nuts currently in use–the all-metal type and the nonmetallic insert type. The Boots and the Flexloc are examples of the all-metal type; the Elastic Stop is an example of the nonmetallic insert type. Figure 10-23 shows several types of self-locking nuts.

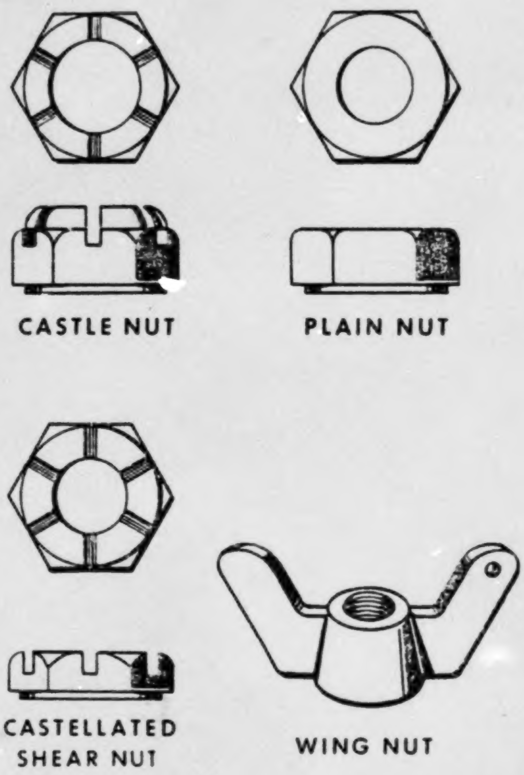

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Figure 10-22.–Nonself-locking nuts.

The Boots self-locking nut is of one-piece all-metal construction, designed to hold tight in spite of severe vibration. It has two sections connected by a spring which is an integral part of the nut. This load carrying and locking nut is so spaced that the two sets of threads are out of phase–that is, so spaced that a bolt which has been screwed through the load carrying section must push the locking section outward against the force of the spring in order to engage the threads of the locking section properly. Thus, the spring, through the medium of the locking section, exerts a constant locking force on the bolt in the same direction as a force that tightens the nut. The nut can be removed and used again without impairing its efficiency. All-metal self-locking nuts are designed to withstand temperatures up to 550° F.

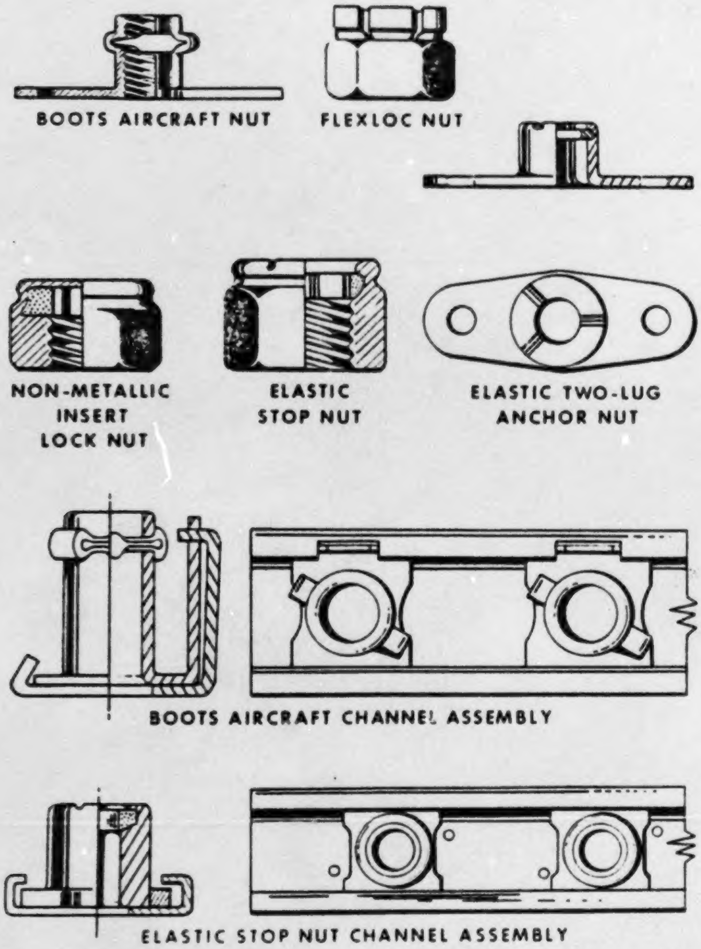
BOOTS AIRCRAFT NUT
FLEXLOC NUT
NON-METALLIC INSERT LOCK NUT
ELASTIC STOP NUT
ELASTIC TWO-LUG ANCHOR NUT
BOOTS AIRCRAFT CHANNEL ASSEMBLY
ELASTIC STOP NUT CHANNEL ASSEMBLY

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Figure 10-23.—Self-locking nuts.

The Elastic Stop nut is constructed with a nonmetallic insert which is designed to lock the nut in place. Two types of inserts are currently in use—the nylon insert and the fiber insert. Both are tough and durable.

The insert is unthreaded and has a smaller diameter than the nut proper. When a screw or a bolt is inserted, contact between the bolt or screw threads and the insert produces the locking action. The elastic stop nut is a low temperature nut and must not be subjected to temperatures above 250° F.

There are certain precautions which must be observed with all self-locking nuts. Bolts, studs, and screws with damaged threads and rough ends must not be used. Bolts, studs, and screws of one-fourth inch or less with cotter pin holes may be used with self-locking nuts only in an emergency, and must be replaced at the earliest possible convenience with the specified type. Bolts, studs, and screws over one-fourth inch diameter may be used with self-locking nuts, provided the cotter pin holes are free from burrs.

Washers

Washers used in aircraft structures may be grouped into three general classes—plain washers, lockwashers, and special washers. Figure 10-24 shows some of the most commonly used types.

Plain washers are widely used under AN hex nuts to provide a smooth bearing surface, to act as a shim in obtaining the correct relationship between the threads of a bolt and the nut, and to adjust the position of castellated nuts with respect to drilled cotter pin holes in bolts. Plain washers are also used under lockwashers to prevent damage to surfaces of soft material.

Lockwashers are used whenever the self-locking or castellated type nut is not used. Sufficient friction is provided by the spring action of the washer to prevent loosening of the nut from vibration. Lockwashers must not be used as part of a fastener for primary or secondary structures. Lockwashers are discussed later in this chapter under safety methods.

Special washers such as ball-socket and seat washers, taper pin washers, and washers for internal-wrenching nuts and bolts are designed for special applications.

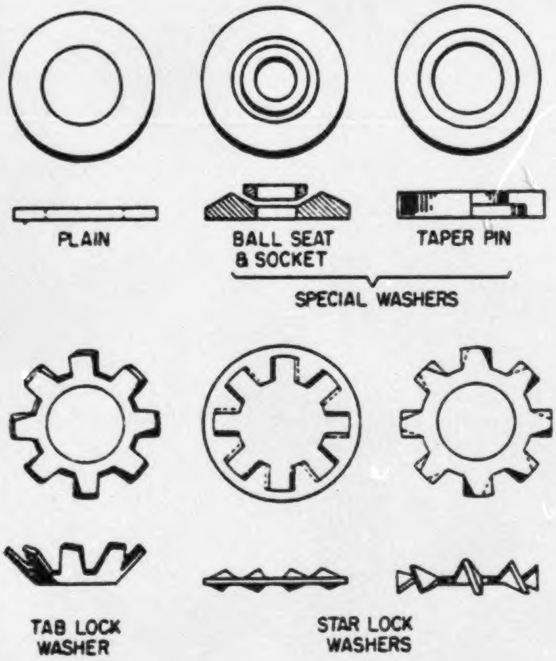

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Figure 10-24.–Various types of washers.

Installation of Nuts and Bolts

Be certain that each bolt is of correct material. Examine the markings on the head to determine whether a bolt is steel or aluminum alloy.

It is of extreme importance to use like bolts in replacement. In every case the applicable Maintenance Instructions Manual and Illustrated Parts Breakdown should be referred to.

Be sure that washers are used under both the heads of bolts and nuts unless their omission is specified. A washer guards against mechanical damage to the material being bolted and prevents corrosion of the structural members. An aluminum alloy washer should be used under the head and nut of a steel bolt securing aluminum alloy or magnesium alloy members. Any corrosion that occurs then attacks the washer rather than the members. Steel washers should be used when joining steel members with steel bolts.

Whenever possile the bolt should be placed with the head on top or in the forward position. This positioning tends to prevent the bolt from slipping out if the nut is accidentally lost.

Be certain that the bolt grip length is correct. Grip length is the length of the unthreaded portion of the bolt shank. Generally speaking, the grip length should equal the thickness of the material being bolted together. Not more than one thread should bear on the material, and the shank should not protrude too far through the nut. Figure 10-25 shows examples of correct and incorrect grip length.

APPLICATION OF TORQUE.–Torque is the amount of twisting force applied when tightening a nut. If torque values are specified in the appropriate manual, a torque wrench must be used. Regardless of whether torque values are specified or not, it is important that all nuts in a particular installation be tightened a like amount. This permits each bolt in a group to carry its share of the load. It is a good practice, therefore, to use a torque wrench in all applications.

SAFETYING OF NUTS AND BOLTS.–It is very important that all nuts, except the self-locking type, be safetied after installation. This prevents nuts from loosening in flight due to vibration. Methods of safetying are discussed later in this chapter.

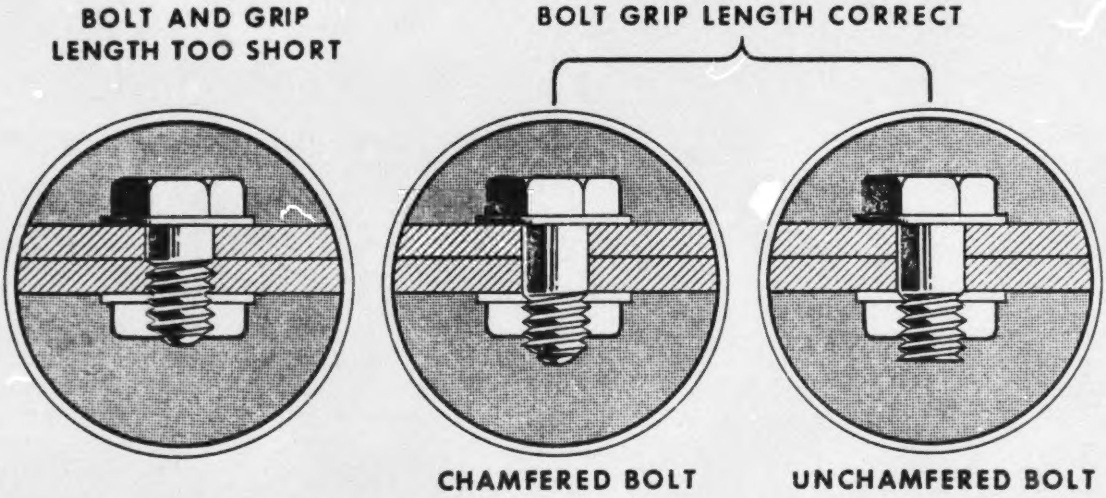

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Figure 10-25.–Correct and incorrect bolt grip length.

Screws

Screws are the most common type of threaded fasteners used on aircraft. They are similar to other types of threaded fasteners, such as bolts, but differ mainly by usually being made of lower strength materials, a looser thread fit, and shanks threaded along the entire length. However, several types of structural screws are available that differ from structural bolts only in the type of head; the material is equivalent, and there is a definite grip.

The countersunk, brazier, and round head screws have various types of slots and recesses, and each type requires a particular type of screwdriver. For proper performance and to prevent mutilation of the screwhead and the screwdriver always use the proper type of screwdriver. Screws may be divided into three main groups: structural screws, machine screws, and self-tapping screws. (See fig. 10-26.)

IDENTIFICATION.–Screws are classified as AN (Air Force-Navy) and NAS (National Aircraft Standard). The diameter, length, type of threads, and material composition of the screw are indicated by a system of letters and digits somewhat similar to the system used for bolts.

In the code number AN500-6-7, the 500 indicates fillister head, coarse thread; the 6 indicates the diameter size (No. 6); and the 7 indicates the length in sixteenths of an inch. Absence of a letter between the 500 and the 6 indicates the material to be carbon steel.

STRUCTURAL SCREWS.–Structural screws are used for assembly of structural parts, as are structural bolts. They are made of alloy steel and are properly heat-treated. Structural screws have a definite grip length and the same shear and tensile strengths as the equivalent size bolt. They differ from structural bolts only in the type of head. These screws are available in roundhead, countersunk-head, and brazier-head types, either slotted or recessed for various types of screwdrivers.

MACHINE SCREWS.–Commonly used machine screws are the roundhead, countersunk head, fillister head, and socket head. All these screws are general purpose screws, and are

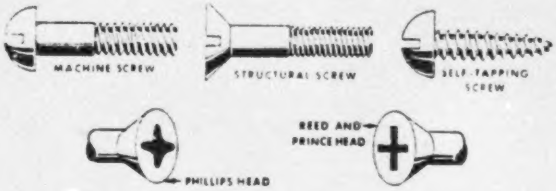

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Figure 10-26.–Screws.

available in low-carbon steel, brass, corrosion-resistance steel, and aluminum alloy. Fillister head screws are usually drilled for safety wire. Socket head screws are designed to be screwed into tapped holes with internal wrenches.

SELF-TAPPING SCREWS.–A self-tapping screw is one that cuts its own internal threads as it is turned into the hole in which it is inserted. Self-tapping screws can be used only in comparatively soft metals and materials. Self-tapping screws may be further divided into two classes or groups–machine self-tapping screws and sheet-metal self-tapping screws.

Machine self-tapping screws (AN504 and AN506) are normally used for attaching removable parts, such as nameplates, to castings. The threads of the screw cut threads in the casting after the hole has been predrilled undersize.

Sheetmetal self-tapping screws (AN530 and AN531) are used for such purposes as temporarily attaching sheet metal for riveting and for permanent assembly of nonstructural assemblies where it is necessary to insert screws in blind application.

CAUTION: Self-tapping screws should never be used to replace standard screws, nuts, bolts, or rivets in the original structure.

TURNLOCK FASTENERS

Turnlock fasteners are used to secure inspection plates, doors, and other removable panels on aircraft. Turnlock fasteners are also referred to by such terms as quick-opening, quick-action, and stressed panel fasteners. The most desirable feature of these fasteners is that they permit quick and easy removal of access panels for inspection and servicing purposes.

Turnlock fasteners are manufactured and supplied by a number of manufacturers under various trade names. Some of the most commonly used are the Dzus, Camloc, and Airloc. The Camloc and Dzus are discussed in this section.

Camloc Fasteners

Camloc fasteners are made in a variety of styles and designs. Included among the most commonly used are the 2600, 2700, 40S51, and 4002 series in the regular line, and the stressed-panel fastener (SPF) in the heavy-duty line. The latter is used in stressed panels; that is, panels which carry structural loads.

The Camloc fastener consists of a stud, grommet, and receptacle or a stud and receptacle only. The stud may be either a flush or nonflush type. Figure 10-27 illustrates the 4002 series fastener, which consists of a stud, grommet, and receptacle.

The stud and grommet are installed in the access door. The receptacle is riveted to the access opening frame, which is attached to the structure of the aircraft. The stud and grommet are installed in a plain, dimpled, countersunk, or counterbored hole, the type of hole being

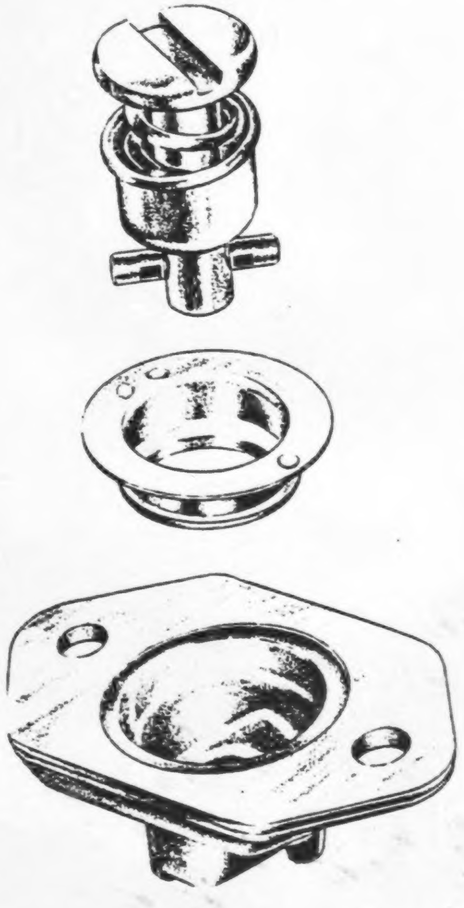

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Figure 10-27.–Camloc 4002 series fastener.

dependent upon location and thickness of the material involved.

A quarter turn of the stud (clockwise) locks the fastener. The fastener may be unlocked only by turning the stud counterclockwise.

Dzus Fasteners

The Dzus fastener consists of a rotatable stud, a permanently mounted spring, and a grommet. The stud and grommet are installed in the access door or other removable part. The spring is riveted to the access-opening frame. (See fig. 10-28.)

Cams of the stud engage with the spring to lock the fastener in the engaged position. The grommet retains the stud in the access door. In some installations, no grommet is used, the stud being secured in position by a snapring, cup washer, or by dimpling the material.

A quarter turn of the stud (clockwise) locks the fastener. The fastener may be unlocked only by turning the stud counterclockwise. A Dzus key or a specially ground screwdriver is used to lock and unlock the fastener.

RIVETS

The fact that there are approximately 75,000 rivets in the airframe of a modern fighter type aircraft and about 150,000 in a patrol type is an indication of how important rivets are in the construction of aircraft. A glance discloses the thousands in the outer skin alone. In addition to the riveted skin, rivets are also used for joining spar sections, for holding rib sections in place, for securing fittings to various parts of the aircraft, and for fastening innumerable bracing members and other parts together.

Two of the major types of rivets used in the aircraft are the standard type, which must be driven using a bucking bar, and the special (blind) rivets, which may be installed where it is impossible to use a bucking bar.

Standard Rivets

These rivets are classified by their head shape, by the material from which they are made, and by their size. Rivet head shapes,

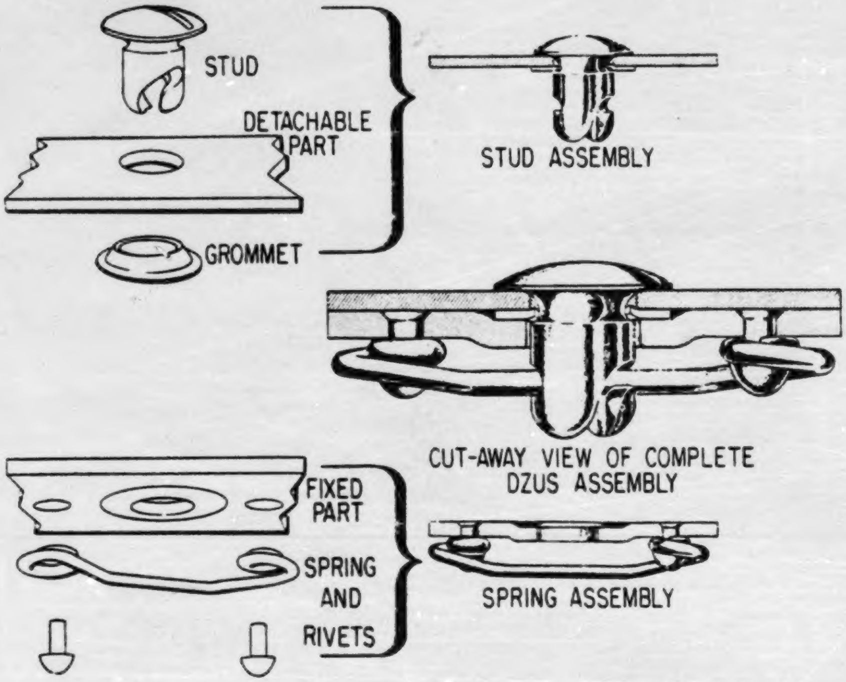

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Figure 10-28.–Dzus fastener.

along with their identifying AN code number, are shown in figure 10-29.

ROUNDHEAD RIVETS.–Roundhead rivets are used on internal structures where strength is the major factor and streamlining is not important.

FLATHEAD RIVETS.–Flathead rivets, like roundhead rivets, are used in the assembly of internal structures where maximum strength is required, but where interference of nearby members does not permit the use of roundhead rivets.

COUNTERSUNK-HEAD RIVETS.–Countersunk rivets, often referred to as flush rivets, are used where streamlining is important. On combat aircraft practically all external surfaces are flush riveted. Countersunk rivets are obtainable with heads having an included angle of 78 and 100 degrees. The 100-degree rivet is the most commonly used type.

BRAZIER-HEAD RIVETS.–Brazier-head rivets offer only slight resistance to the airflow and are therefore frequently used on external surfaces, especially on noncombat-type aircraft.

UNIVERSAL-HEAD RIVETS.–Universal-head rivets are similar to brazier-head rivets and are to be used in place of all other protruding-head rivets when existing stocks are depleted.

Most of the rivets used in aircraft construction are made of aluminum alloy. A few types, used for special purposes, are made of mild steel, Monel, titanium, and copper. Of the aluminum alloys, rivets made of alloys 1100, 2117, 2017, 2024, 5053, and 5056 are considered standard. These alloys are usually identified by markings on the head or shank of the rivet.

Further information concerning rivet alloys, sizes, and the rivet code can be obtained by referring to Aviation Structural Mechanic S 3 & 2.

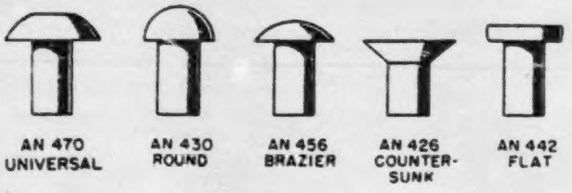

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Figure 10-29.–Rivet head shapes and code numbers.

Special (Blind) Types

There are many places on an aircraft where access to both sides of a riveted structural part is impossible, or where limited space does not permit the use of a bucking bar. Furthermore, in the attachment of many nonstructural parts, such as aircraft interior furnishings, flooring, deicing boots, flotation equipment, and the like, the full strength of solid shank rivets is not necessary and their application adds much extra weight.

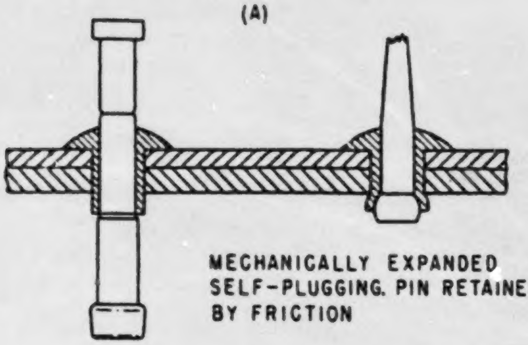
For use in such places, rivets have been designed which can be formed from the outside. They are lighter than solid shank rivets, yet amply strong. Such rivets are commonly referred to as blind rivets because of the self-heading feature. Figure 10-30 illustrates the three general types of blind rivets discussed in this section. Rivet A, referred to as a self-plugging rivet (friction lock), is discussed first.

SELF-PLUGGING RIVETS (FRICTION LOCK).–The self-plugging rivet (friction lock) retains the stem in position by friction. The stem is drawn up into the rivet shank and the mandrel portion of the stem upsets the shank on the blind side, forming a plug in the hollow center of the rivet. The excess portion of the stem breaks off at a groove due to the continued pulling action of the rivet tool. The remainder of the stem must be trimmed with a cutter. The two styles of rivet heads are 100-degree counter-sunk and universal. The most commonly used rivet in this class is the Cherry rivet. Figure 10-31 illustrates the installation of the Cherry rivet.

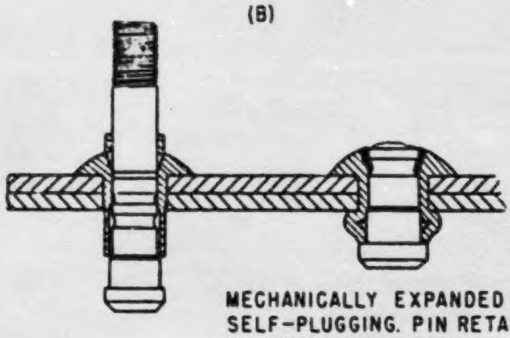
Self-plugging rivets (friction lock) should not be used on control surface hinge brackets, wing attachment fittings, landing gear fittings, fixed tail surfaces attachment fittings or in other similar heavily stressed locations. These rivets also should not be used in hulls, floats, or tanks where fluid-tight joints are required.

Self-plugging rivets (friction lock) can be installed with either a handtool or a power tool. Both hand and power tools are illustrated in figure 10-32.

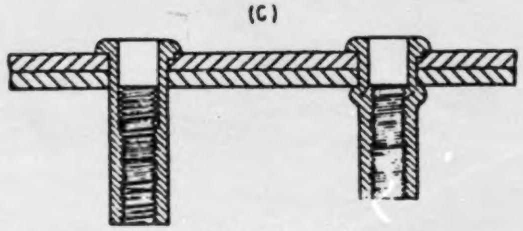
SELF-PLUGGING RIVETS (MECHANICAL LOCK).–Rivet B in figure 10-30 is a blind rivet that operates on the same principle as rivet A, both employing a mandrel stem and hollow shank. The main difference in A and B



MECHANICALLY EXPANDED SELF-PLUGGING. PIN RETAINED BY FRICTION



MECHANICALLY EXPANDED SELF-PLUGGING. PIN RETAINED BY MECHANICAL LOCK



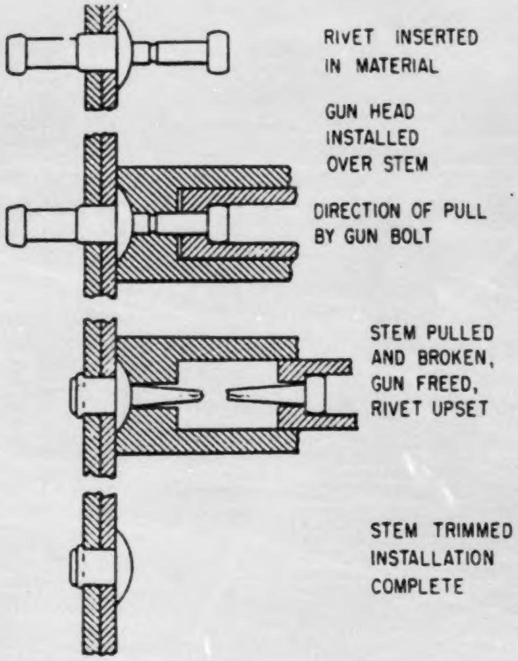
MECHANICALLY EXPANDED RIVNUT

AN.172

Figure 10-30.–Types of blind rivets.

is the method of pin retention: rivet A relies on friction for pin retention, while rivet B employs a mechanical lock between the head of the rivet and the pull stem. Figure 10-33 illustrates the forming of this mechanical lock.

Rivets included under this classification are the Huck and Olympic. They are manufactured in 1/8-, 5/32-, and 3/16-inch diameters in brazier-head and countersunk-head styles.


RIVET INSERTED IN MATERIAL
GUN HEAD INSTALLED OVER STEM
DIRECTION OF PULL BY GUN BOLT
STEM PULLED AND BROKEN, GUN FREED, RIVET UPSET
STEM TRIMMED INSTALLATION COMPLETE

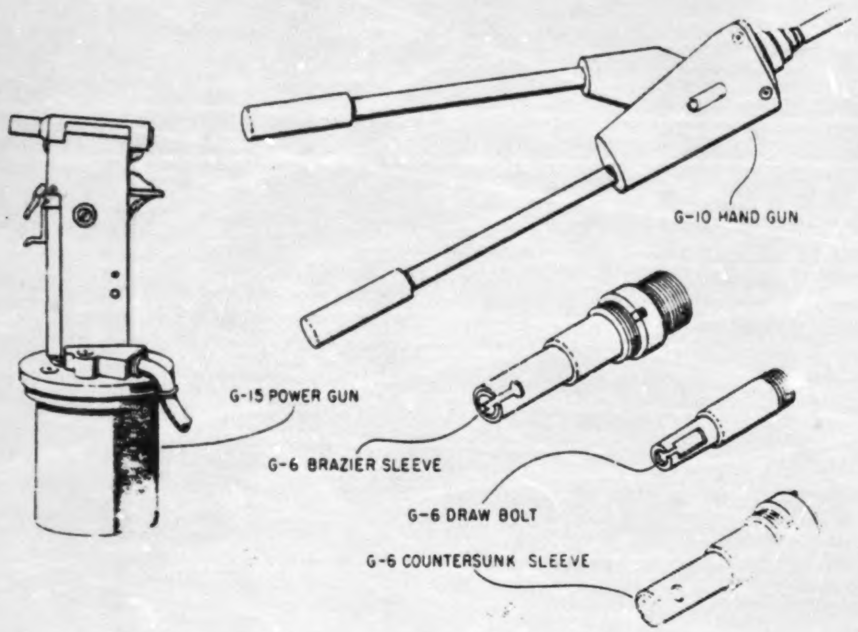
AN.173

Figure 10-31.–Self-plugging rivet (friction lock) installation.

The loads allowable for the self-plugging rivet (mechanical lock) are comparable to those for solid shank rivets of the same shear strength regardless of sheet thickness. Pin retention characteristics are excellent in these rivets and the possibility of the pin working out is minimized by the lock formed in the rivet head.

This rivet is installed by power tools only. Figure 10-34 shows the type power tool used with these rivets.

RIVNUTS.–The Rivnut is a hollow rivet which is counterbored and threaded on the inside. Installation is accomplished with the aid of a special tool, which heads the rivet on the blind side of the work. Rivnuts are primarily used as a nut plate, as in the attachment of deicer boots; however, they may be used as rivets in secondary structures such as instruments, brackets and soundproofing materials. After a suitable group of Rivnuts has been installed, accessories can be fastened in place with screws.

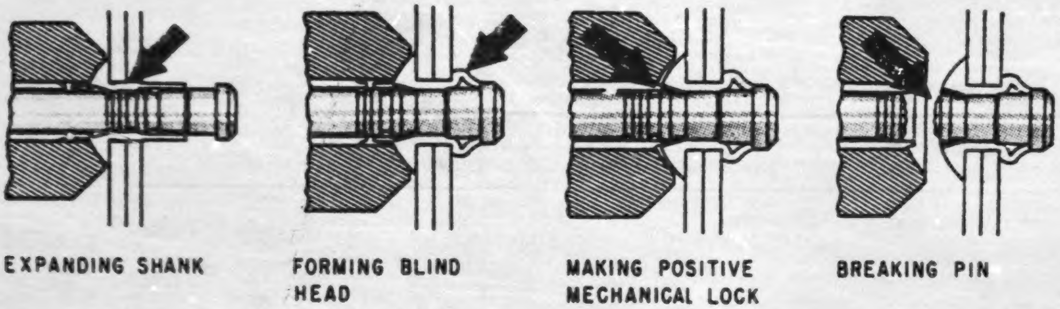

G-10 HAND GUN
G-15 POWER GUN
G-6 BRAZIER SLEEVE
G-6 DRAW BOLT
G-6 COUNTERSUNK SLEEVE

AN.174

Figure 10-32.–Self-plugging rivet (friction lock) installation tools.

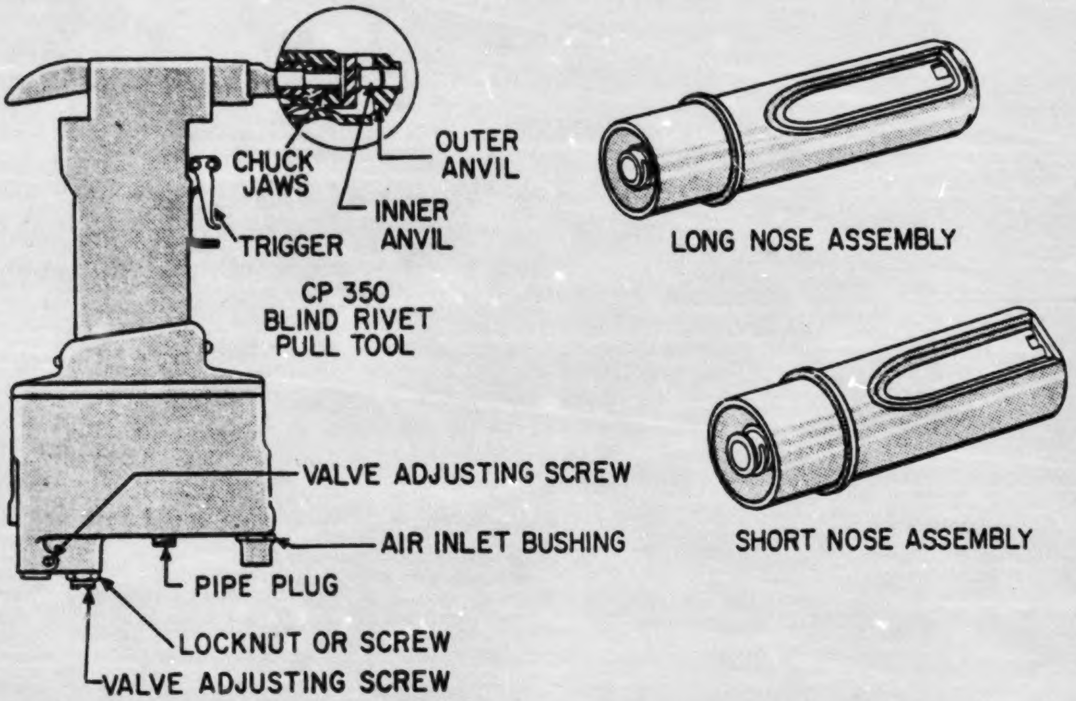
Rivnuts are manufactured in two head styles as shown in figure 10-35. Both the countersunk and flathead styles are made in three sizes and all sizes come in a variety of grip lengths. Rivnuts are available with or without keys. Keys are small projections attached to the head to keep the Rivnut from turning. Keyed Rivnuts are used when the Rivnut serves as a nut plate, while Rivnuts without keys are used for blind riveting jobs where no torque loads are imposed.

Tools used in the installation of Rivnuts include the heading tool and the keyway cutter. The heading tool (fig. 10-36) has a threaded mandrel onto which the Rivnut is threaded until the head of the Rivnut is against the anvil of the heading tool. The keyway cutter is used for cutting a notch in the Rivnut hole for the Rivnut


EXPANDING SHANK
FORMING BLIND HEAD
MAKING POSITIVE MECHANICAL LOCK
BREAKING PIN

AN.175

Figure 10-33.–Forming of self-plugging rivet head (mechanical lock).


CHUCK JAWS
OUTER ANVIL
INNER ANVIL
TRIGGER
CP 350 BLIND RIVET PULL TOOL
LONG NOSE ASSEMBLY
SHORT NOSE ASSEMBLY
VALVE ADJUSTING SCREW
AIR INLET BUSHING
PIPE PLUG
LOCKNUT OR SCREW
VALVE ADJUSTING SCREW

AN.176

Figure 10-34.–Self-plugging rivet (mechanical lock) installation tool.

key. In cases where the metal is too thick to use the keyway cutter, a small round file can be used to cut the keyway.

CONTROL CABLES

Cables are the most widely used linkage in primary flight control systems. Cable type linkage is also used in engine controls, emergency extension systems for the landing gear, and various other systems throughout the modern aircraft.

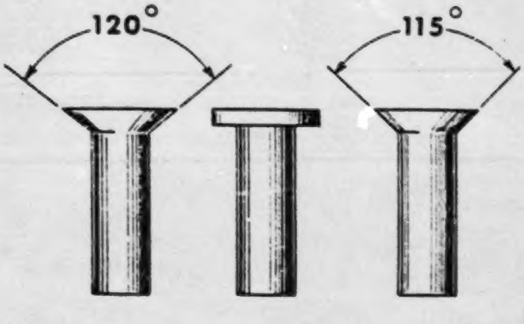
Cable type linkage has several advantages over the other types. It is strong and light in weight, and its flexibility makes it easy to route through the aircraft. An aircraft cable has a high mechanical efficiency and can be set up without backlash, which is very important for precise control.

Cable linkage also has some disadvantages. Tension must be adjusted frequently due to stretching and temperature changes.

Aircraft control cables are fabricated from carbon steel or stainless steel. The present-day trend is to use stainless steel in naval aircraft.

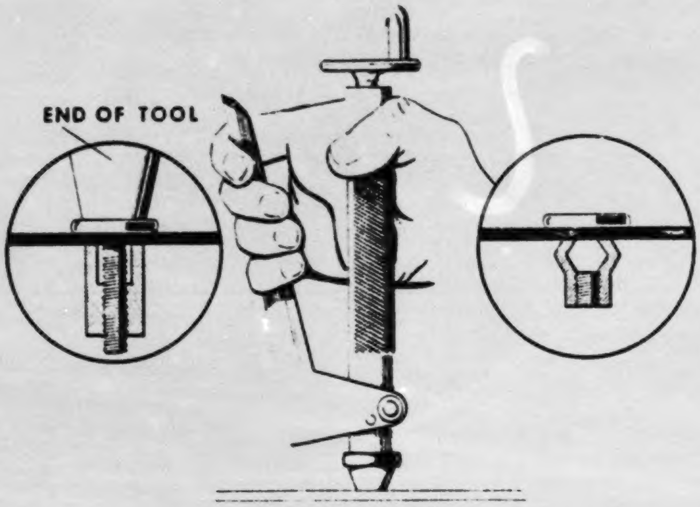
Cable Construction

The basic component of a cable is a wire. The diameter of the wire determines the total diameter of the cable. A number of wires are preformed into a helical or spiral shape and then formed into a strand. These preformed strands are laid around a straight center strand to form the cable.



AN.177

Figure 10-35.–Rivnut heads.



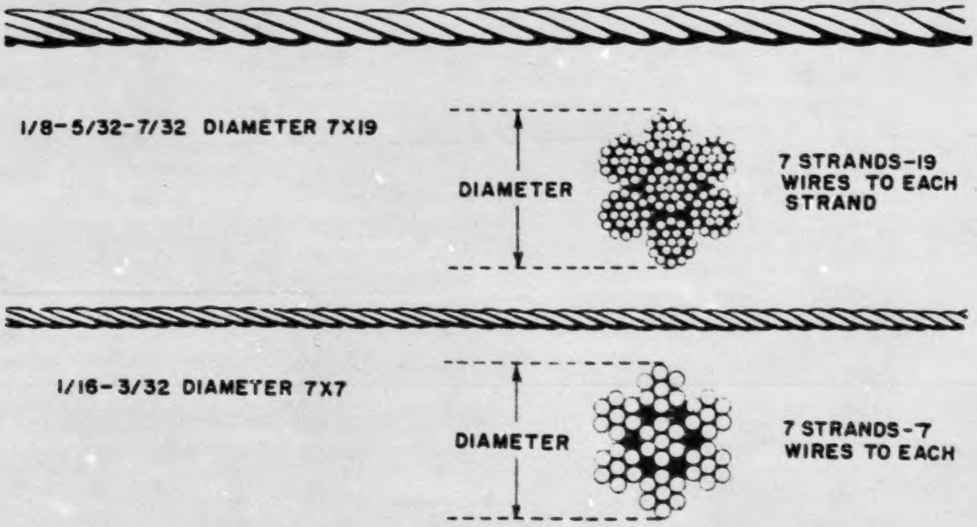
AN.178

Figure 10-36.–Hand-operated Rivnut heading tool.

Cable designations are based on the number of strands and the number of wires in each strand. The most common aircraft cables are the 7 x 7 and 7 x 19.

The 7 x 7 cable consists of 7 strands of 7 wires each. Six of these strands are laid around the center strand. (See fig. 10-37.) This is a cable of medium flexibility and is used for trim tab controls, engine controls, and indicator controls.

The 7 x 19 cable is made up of 7 strands of 19 wires each. Six of these strands are laid around the center strand. (See fig. 10-37.) This cable is extra flexible and is used in primary


1/8-5/32-7/32 DIAMETER 7X19
DIAMETER
7 STRANDS-19 WIRES TO EACH STRAND
1/16-3/32 DIAMETER 7X7
DIAMETER
7 STRANDS-7 WIRES TO EACH

AN.179

Figure 10-37.–Cable cross sections.

control systems and in other places where operation over pulleys is frequent.

Aircraft control cables vary in diameter, ranging from one-sixteenth to three-eights inch. The diameter is measured as shown in figure 10-37.

Cable Fittings

Cables may be equipped with several different types of fittings such as terminals, thimbles, bushings, and shackles.

Terminal fittings are generally of the swaged type. They are available in the threaded end, fork end, eye end, single-shank ball end, and double-shank ball end. The threaded end, fork end, and eye end terminals are used to connect the cable to a turnbuckle, bellcrank, or other linkage in the system. The ball end terminals are used for attaching cables to quadrants and special connections where space is limited. Figure 10-38 illustrates the various types of terminal fittings.

The thimble, bushing, and shackle fittings may be used in place of some types of terminal fittings when facilities and supplies are limited and immediate replacement of the cable is necessary.

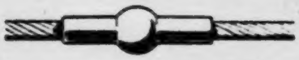
Attachment of these cable fittings and cable linkage maintenance are discussed in Aviation Structural Mechanic S 3 & 2.

Turnbuckles

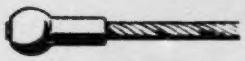
A turnbuckle is a mechanical screw device consisting of two threaded terminals and a threaded barrel. Figure 10-39 illustrates a typical turnbuckle assembly

Turnbuckles are fitted in the cable assembly for the purpose of making minor adjustments in cable length and for adjusting cable tension. One of the terminals has right-hand threads and the other has left-hand threads. The barrel has matching right- and left-hand internal threads. The end of the barrel with the left-hand threads can usually be identified by a groove or knurl around that end of the barrel.

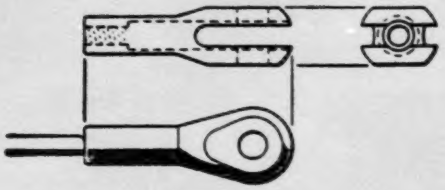
When installing a turnbuckle in a control system, it is necessary to screw both of the terminals an equal number of turns into the barrel. It is also essential that all turnbuckle terminals be screwed into the barrel at least until not more than three threads are exposed.



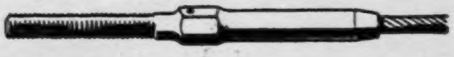
AN 663 DOUBLE SHANK BALL END TERMINAL



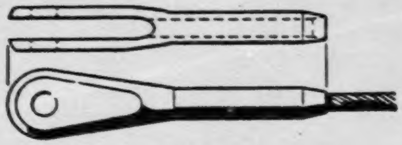
AN 664 SINGLE SHANK BALL END TERMINAL



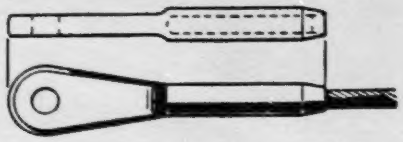
AN 665 ROD END TERMINAL



AN 666 THREADED CABLE TERMINAL



AN 667 FORK END CABLE TERMINAL



AN 668 EYE END CABLE TERMINAL

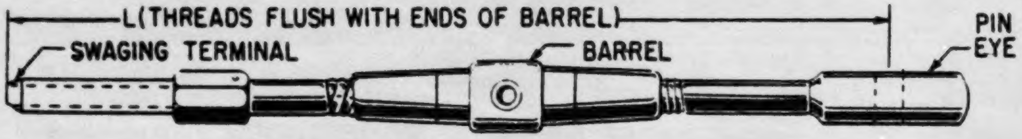
AN.180

Figure 10-38.–Types of terminal fittings.

After a turnbuckle is properly adjusted, it must be safetied. The methods of safetying turnbuckles are discussed later in this chapter.

PUSH-PULL TUBE LINKAGE

Push-pull tubes are used as linkage in various types of mechanically operated systems. This type linkage eliminates the problem of varying tension and permits the transfer of either compression or tension stress through a single tube. One of the most common uses of push-pull tubes is on the aileron system of aircraft having folding type wings.



AN.181

Figure 10-39.–Typical turnbuckle assembly.

A push-pull tube assembly consists of a hollow aluminum alloy or steel tube with an adjustable end fitting and a checknut at either end. (See fig. 10-40.) The checknuts are for the purpose of securing the end fittings after the tube assembly has been adjusted to its correct length. Push-pull tubes are generally made in short lengths to prevent vibration and bending under compression loads.

TORQUE TUBES

Torque tube linkage may be used on either manually operated or electrically operated trim tab systems. On a manually operated system the torque tubes are used to transmit the motion from a control in the cockpit to the trim tab. On an electrically operated system they transmit motion from an electric actuator located in the vicinity of the control surface and energized through a switch in the cockpit.

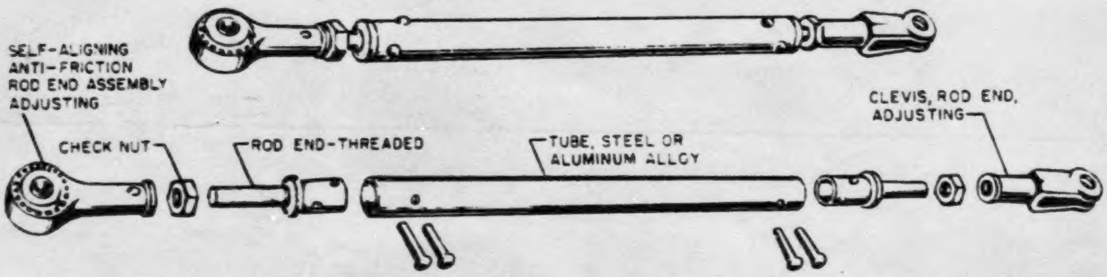
This type trim tab system consists of a series of torque tube assemblies linked by universal joints and gearboxes or angle-drive units. The torque tube linkage terminates at a jackscrew actuator which connects to the tab. This jackscrew actuator converts the rotary motion of the torque tubes to linear motion, thus moving the tab.

AIRCRAFT ELECTRICAL SYSTEM HARDWARE

Wire and Cable

An important part of aircraft electrical maintenance is determining the correct wire or cable for a given job. For purposes of electrical installations a wire is described as a stranded conductor, covered with an insulating material. The term cable, as used in aircraft electrical installations, includes the following: two or more insulated conductors contained in the same jacket (multiconductor cable); two or more insulated conductors twisted together (twisted pair); one or more insulated conductors covered with a metallic braided shield (shielded cable); a single insulated conductor with a metallic braided outer conductor (RF cable).

For wire replacement work, the aircraft Maintenance Instructions Manual should first be consulted since it normally lists the wire used in a given aircraft. When this information cannot be obtained from the applicable manual, you must select the correct size and type of wire needed. The factors used in determining correct wire size are explained in Basic Electricity, NavPers 10086-B.


SELF-ALIGNING ANTI-FRICTION ROD END ASSEMBLY ADJUSTING
CHECK NUT
ROD END-THREADED
TUBE, STEEL OR ALUMINUM ALLOY
CLEVIS, ROD END, ADJUSTING

AN.182

Figure 10-40.–Push-pull tube assembly.

Connectors

Connectors are devices attached to the ends of cables and sets of wires to make them easier to connect and disconnect. Connectors consist of two portions–the fixed portion, called the receptacle, and the movable portion, called the plug. Each connector consists of a plug assembly and a receptable assembly. The two assemblies are coupled by means of a coupling nut, and each consists of an aluminum shell containing an insulating insert which holds the current-carrying contacts. The plug is usually attached to the cable end and is the part of the connector on which the coupling nut is mounted. The receptacle is the half of the connector to which the plug is connected and is usually mounted on a part of the equipment. One type of connector which is commonly used in aircraft electrical systems is shown in figure 10-41.

Terminals

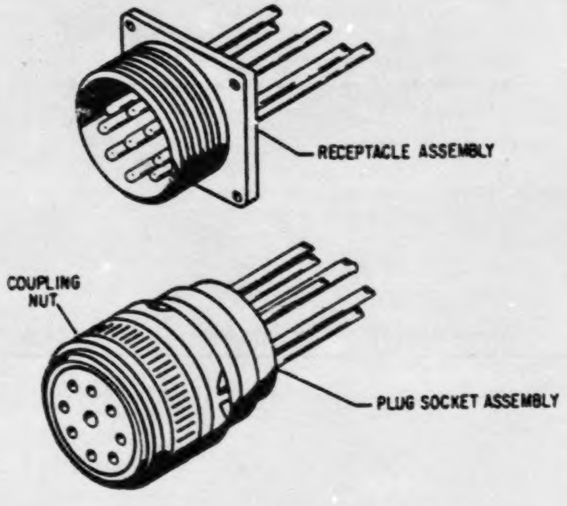
Since most aircraft wires are stranded, it is necessary to use terminal lugs to hold the strands together and facilitate fastening the wires to terminal studs. The terminals used in electrical wiring are either of the soldered or crimped type. Terminals used in repair work must be of the size and type specified in the applicable Maintenance Instructions Manual. The crimped type terminals are generally recommended for use on naval aircraft. Soldered type terminals are usually used in emergencies only.

The basic types of solderless terminals are shown in figure 10-42; (A) shows the straight type, (B) the right angle type, (C) the flag type, and (D) the splice type. There may be variations of these types.

Bonding

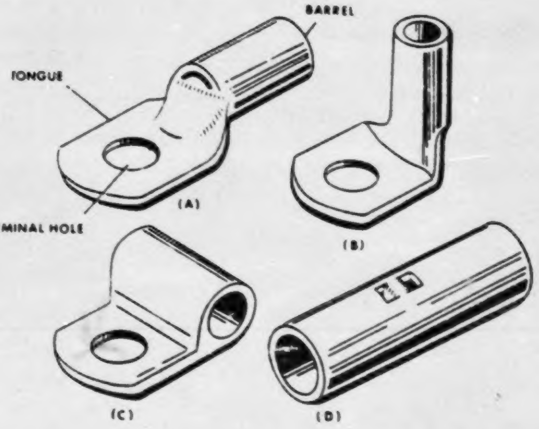
Bonding is the connecting together of all the metal parts of an aircraft to complete an electrical unit. Bonding connections are made of screws, nuts, washers, clamps, and bonding jumpers. Figure 10-43 shows a typical bonding installation.

An aircraft can become highly charged with static electricity while in flight, and if the aircraft is improperly bonded, all metal parts do not have the same amount of static charge. A difference of potential exists between the various metal surfaces. If the resistance between insulated metal surfaces is great enough, charges can accumulate until the potential difference becomes high enough to cause a spark. This constitutes a fire hazard and also causes radio interference. If lightning strikes an aircraft, a good conducting path is necessary for heavy current to minimize severe arcs and sparks.



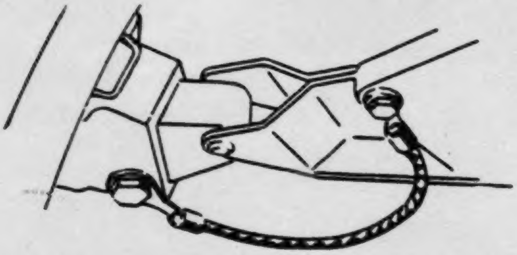
AN.183

Figure 10-41.–Connector assembly.



AN.184

Figure 10-42.–Basic types of solderless terminals.



AN.185

Figure 10-43.–Typical bonding link installation.

Bonding also provides the necessary low-resistance return path for single wire electrical systems. This low-resistance path provides a means of bringing the entire aircraft to the earth's potential when it is grounded.

Whenever you perform an inspection, both bonding connections and safetying devices must be inspected with great care.

SAFETY METHODS

Safetying is a process of securing all aircraft bolts, nuts, machines, and capscrews, studs, and other fastenings so that they do not work loose due to vibration. Loose bolts, nuts, or screws can ruin engines or cause parts of the aircraft to drop off. In order to carry out an inspection of equipment on an aircraft, you must be familiar with the various methods and means of safetying such equipment. Careless safetying is a sure road to disaster. Therefore, always use the proper method for safetying; safety a part you have just unsafetied before going on to the next item of inspection; and inspect for proper safetying throughout the aircraft.

There are various methods of safetying aircraft parts. The most widely used methods are safety wire, cotter pins, lockwashers, snaprings, and special nuts, such as self-locking nuts, pal nuts, and jamnuts. Some of these nuts and washers have been previously described in this chapter.

Safety Wiring

Safety wire is the most positive and satisfactory method of safetying capscrews, studs, nuts, boltheads, and turnbuckle barrels which cannot be safetied by any other practical means. It is a method of wiring together two or more units in such a manner that any tendency of one to loosen is counteracted by the tightening of the wire.

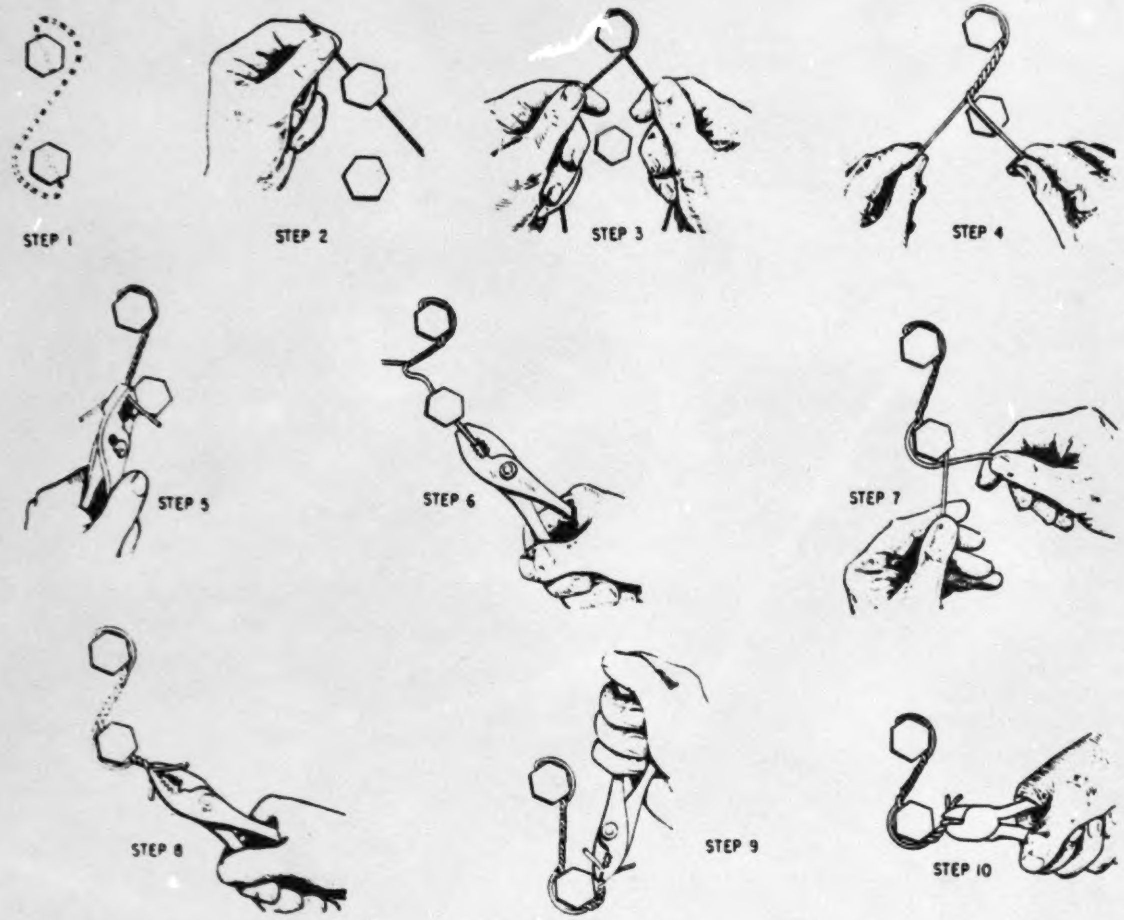
NUTS, BOLTS, AND SCREWS.–Nuts, bolts, and screws are safety wired by the single wire or double twist method. The double twist method is the most common method of safety wiring. The single wire method may be used on small screws in a closely spaced, closed geometrical pattern, parts in electrical systems, and in places that are difficult to reach that make the single wire method more advisable.

The following is a standard double-twist safety wire installation method for two bolts with right-hand threads. Figure 10-44 illustrates this safety wire installation.

1. Assemble the unit. Torque the bolts, taking care to align the safety wire holes as shown in step 1, figure 10-44.
2. Insert the proper size wire through the hole in the first bolt (step 2).
3. Bend the left end of the wire clockwise around the bolthead under the other end of the wire (step 3).
4. Pull the loop tight against the bolthead with the pliers. Grasping both ends of the wire, braid (twist) them in a clockwise direction until the end of the braid is just short of reaching the second bolt (step 4).
5. Check to insure that the loop is still tightly in place around the first bolthead. Grasp the wire with the pliers just beyond the end of the braid and, while holding it taut, twist in a clockwise direction until the braid is stiff (step 5).

NOTE: The braid must be tight enough to resist friction or vibration wear but should not be overtightened.

6. Insert the upper end of the safety wire through the hole in the second bolt. Pull until the braid is taut (step 6).
7. Bring the other end of the wire counterclockwise around the bolthead and under the protruding wire end (step 7).
8. Tighten the loop and braid the wire ends in a clockwise direction. Grasp the wire with the pliers just beyond the end of the braid and twist in a clockwise direction until the braid is stiff, while keeping the wire under tension (step 8).



AN.186

Figure 10-44.–Standard double-twist safety wire installation procedure.

9. With a final twisting motion, bend the braid to the right and against the head of the bolt (step 9).

10. Cut the braid, being careful that between three and six full twists still remain. Avoid sharp projecting ends.

Figure 10-45 is an illustration of various methods which are commonly used in safety wiring nuts, bolts, and screws.

1. Examples 1, 2, and 5 of figure 10-45 illustrate the proper method of safety wiring bolts, screws, square head plugs, and similar parts when wired in pairs.

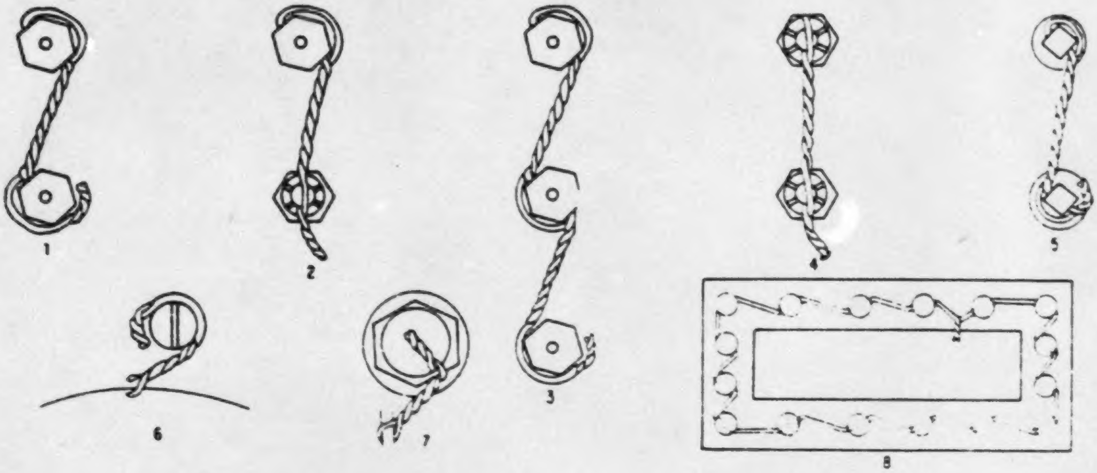
2. Examples 6 and 7 illustrate a single-threaded component wired to a housing or lug.

3. Example 3 illustrates several components wired in series.

4. Example 4 illustrates the proper method of wiring castellated nuts and studs. Note that there is no loop around the nut.

5. Example 8 illustrates several components in a closely spaced, closed geometrical pattern, using the single-wire method.

When drilled-head bolts, screws, or other parts are grouped together they are more conveniently safety wired to each other in a series rather than individually. The number of nuts, bolts, or screws that may be safety wired together is dependent on the application. For instance, when safety-wiring widely spaced bolts



AN.187

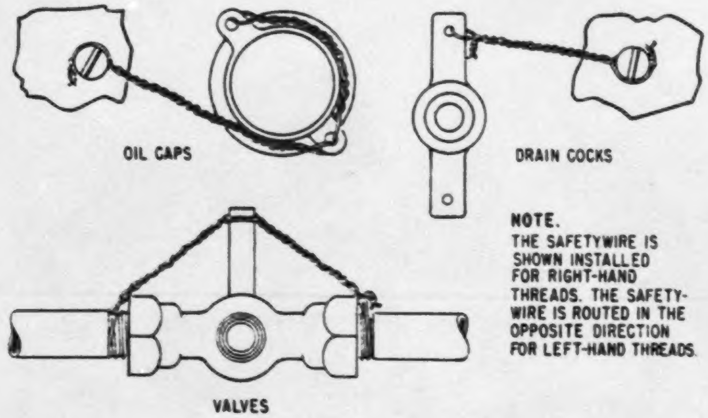
Figure 10-45.–Safety wiring methods.

by the double twist method, a group of three should be the maximum number in a series.

When safety-wiring closely spaced bolts, the number that can be safety-wired by a 24-inch length of wire is the maximum in a series. The wire is arranged in such a manner that if the bolt or screw begins to loosen, the force applied to the wire is in the tightening direction.

Parts being safety-wired should be torqued to recommended values and the holes aligned before attempting to proceed with the safetying operation. Never overtorque or loosen a torqued nut to align safety wire holes.

OIL CAPS, DRAIN COCKS, AND VALVES.– These units are safety wired as shown in figure 10-46. In the case of the oil cap, the wire is anchored to an adjacent fillister head screw. This system applies to any other unit which must be safety wired individually. Ordinarily, anchorage lips are conveniently located near



NOTE.
THE SAFETYWIRE IS SHOWN INSTALLED FOR RIGHT-HAND THREADS. THE SAFETY-WIRE IS ROUTED IN THE OPPOSITE DIRECTION FOR LEFT-HAND THREADS.

AN.188

Figure 10-46.–Safety wiring oil caps, drain cocks, and valves.

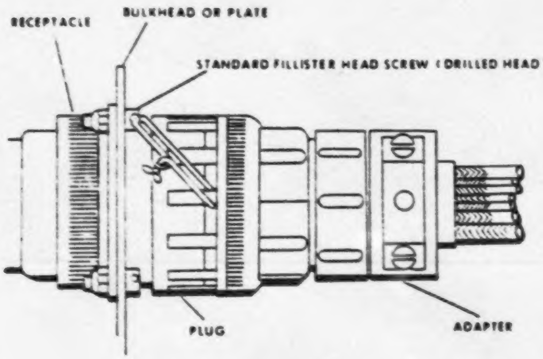
these individual parts. When such provision is not made, the safety wire is fastened to some adjacent part of the assembly.

ELECTRICAL CONNECTORS.–Under conditions of severe vibration, the coupling nut of a connector may vibrate loose; and with sufficient vibration the connector comes apart. When this occurs, the circuit carried by the cable opens. The proper protective measure to prevent this occurrence is by safety wiring as shown in figure 10-47. The safety wire should be as short as practicable and must be installed in such a manner that the pull on the wire is in the direction which tightens the nut on the plug.

TURNBUCKLES.–After a turnbuckle has been properly adjusted, it must be safetied. There are several methods of safetying turnbuckles; however, only two methods have been adopted by the services. These methods are illustrated in figure 10-48 (A) and 10-48 (B). The clip-locking method (fig. 10-48 (A)) is used only on the most modern aircraft. An example of an aircraft using this method is the RA-5C. These aircraft use a new type turnbuckle that is designed for use with the wire clip. The older type aircraft still utilize the type turnbuckles that require the wire-wrapping method.

Detailed instructions for using both the clip-locking and the wire-wrapping methods of safetying turnbuckles may be found in Aviation Structural Mechanic S 3 & 2.

GENERAL SAFETY WIRING RULES.–When using the safety wire method of safetying, the following general rules should be followed:



AN.189

Figure 10-47.–Safety wiring attachment for plug connectors.

1. A pigtail of one-fourth to one-half inch (3 to 6 twists) should be made at the end of the wiring. This pigtail must be bent back or under to prevent it from becoming a snag.
2. The safety wire must be new upon each application.
3. When castellated nuts are to be secured with safety wire, tighten the nut to the low side of the selected torque range, unless otherwise specified, and if necessary, continue tightening until a slot aligns with the hole.
4. All safety wires must be tight after installation, but not under such tension that normal handling or vibration will break the wire.
5. The wire must be applied so that all pull exerted by the wire tends to tighten the nut.
6. Twists should be tight and even, and the wire between the nuts as taut as is possible without overtwisting.

Cotter Pin Safetying

Cotter pin installation is shown in figure 10-49. Castellated nuts are used with bolts that have been drilled for cotter pins. Stainless steel cotter pins should be used. The cotter pin should fit neatly into the hole, with very little sideplay. The following general rules apply to cotter pin safetying:

The prong bent over the bolt end should not extend beyond the bolt diameter. (Cut it off if necessary.)

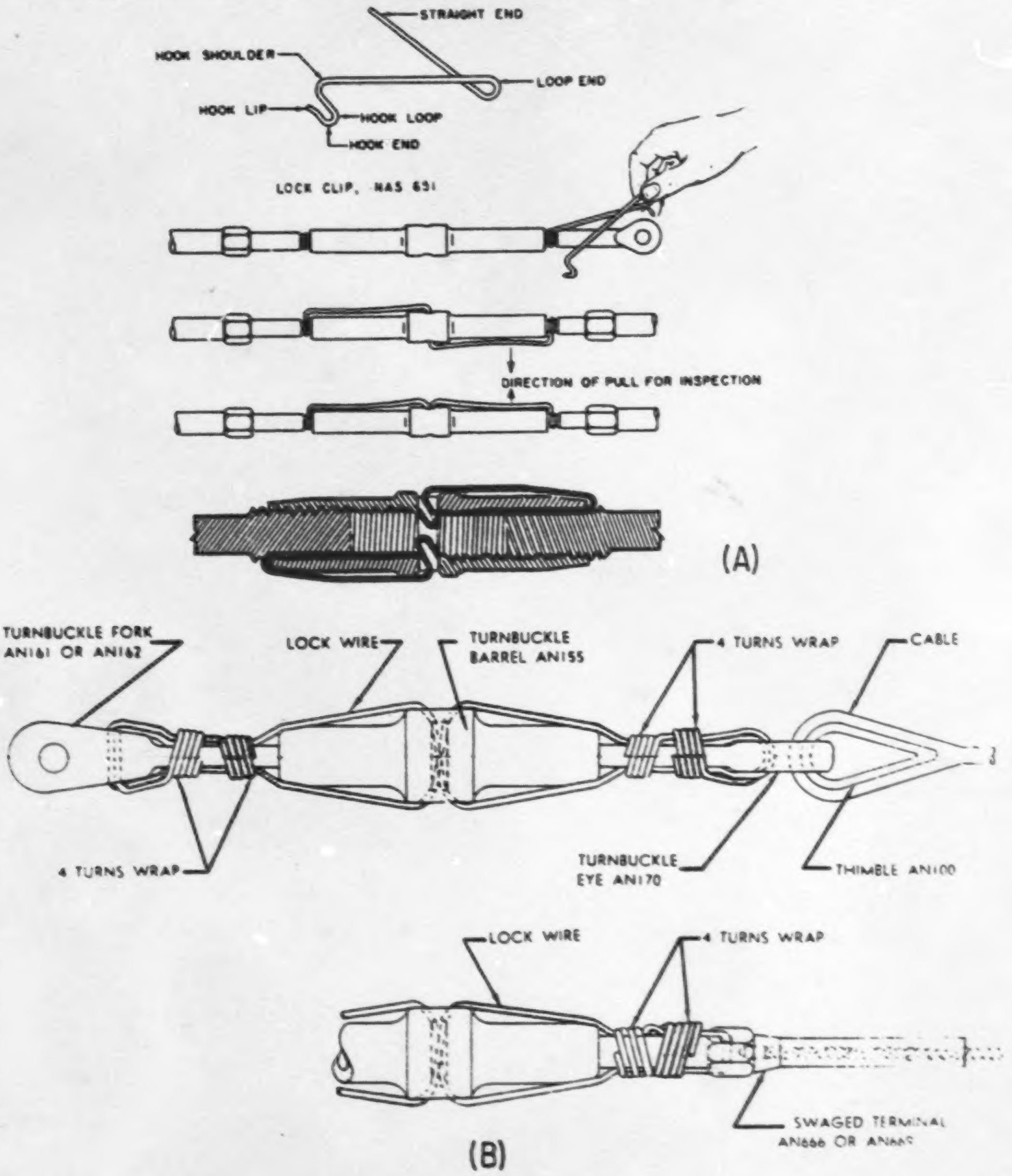
The prong bent down should not rest against the surface of the washer. (Again cut it off if necessary.)

If the optional wraparound method is used, the prongs should not extend outward from the sides of the nut.

All prongs should be bent over a reasonable radius. Sharp angled bends invite breakage. Tapping lightly with a mallet is the best method of bending the prongs.

Lockwashers

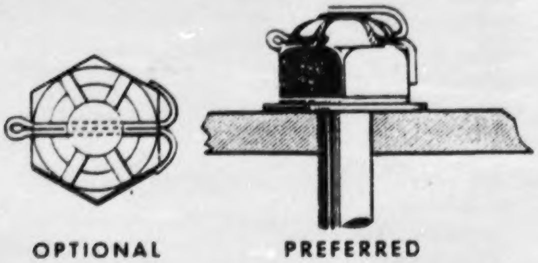
Lockwashers are used with machine screws, plain hex nuts, and boltheads whenever the self-locking or castellated type of nut is not applicable. Sufficient friction is provided by the spring action or the turned-up tabs to prevent loosening of the unit due to vibration.


STRAIGHT END
HOOK SHOULDER
LOOP END
HOOK LIP
HOOK LOOP
HOOK END
LOCK CLIP, NAS 651
DIRECTION OF PULL FOR INSPECTION
(A)
TURNBUCKLE FORK AN161 OR AN162
LOCK WIRE
TURNBUCKLE BARREL AN155
4 TURNS WRAP
CABLE
4 TURNS WRAP
TURNBUCKLE EYE AN170
THIMBLE AN100
LOCK WIRE
4 TURNS WRAP
SWAGED TERMINAL AN666 OR AN669
(B)

AN.190

Figure 10-48.–Safetying turnbuckles. (A) Clip-locking method; (B) wire-wrapping method.

STAR LOCKWASHERS.–The star lock or shakeproof washer is a round washer made of hardened and tempered carbon steel, stainless steel, or Monel. This washer can have either internal or external teeth. Each tooth is twisted, one edge up and one edge down. The top edge bites into the nut or bolt and the bottom edge bites into the working surface. It depends on spring action for its locking feature. This washer can be used only once because the teeth



AN.191
Figure 10-49.–Cotter pin installations.

become somewhat compressed after being used. Star lockwashers are illustrated in figure 10-24.

TAB LOCKWASHERS.–Tab lock or tabwashers are round washers designed with tabs or lips that are bent upwards across the sides of a hex nut or bolt to lock the nut in place. There are various methods of securing the tabwasher to prevent it from turning, such as an external tab bent downward 90° into a small hole in the face of the unit, an internal tab which fits a keyed bolt, or two or more tabwashers connected by a bar.

Tabwashers can withstand higher heat than other methods of safetying and can be used under high vibration conditions safely.

Tabwashers should be used only once because the tabs tend to crystalize when bent a second time.

Snaprings

A snapring is a ring of metal, either round or flat in cross section, which is tempered to have spring like action. This spring like action will hold the snapring firmly seated in a groove. The external types are designed to fit in a groove around the outside of a shaft or cylinder. The internal types fit in a groove inside a cylinder. A special type of pliers is designed to install each type of snapring.

Snaprings can be reused as long as they retain their shape and spring like action.

External type snaprings may be safety wired but internal types are never safetied. Safety wiring of an external type snapring is shown in figure 10-50.

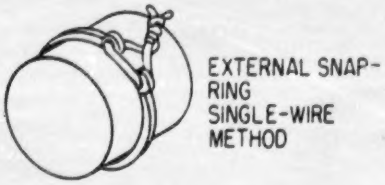


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Figure 10-50.–External type snapring with safety wire installed.